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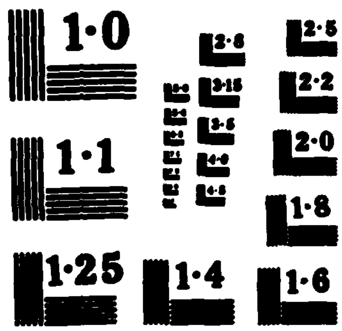
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INVESTIGATION OF THE CHARACTERISTICS OF SMALL SWATH SHIPS CONFIGURED FOR UNITED STATES COAST GUARD MISSIONS

JUNE 1983

FINAL REPORT

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16. Abstract

AS PART OF AN EFFORT TO EXAMINE ADVANCED VEHICLES CONFIGURED FOR UNITED STATES COAST GUARD (USCG) MISSIONS, THE COAST GUARD MARINE VEHICLE TECHNOLOGY BRANCH, OFFICE OF RESEARCH AND DEVELOPMENT, TASKED THE SWATH PROJECT OFFICE AT THE DAVID TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER TO PERFORM A STUDY EXAMINING THE APPLICABILITY OF THE SWATH CONCEPT TO THESE MISSIONS. THE APPROACH TAKEN IN PERFORMING THIS STUDY WAS TO DEVELOP FOUR SWATH CONCEPTS CONFIGURED FOR COAST GUARD MISSIONS AND USE THESE FOUR CONCEPTS AS A FOUNDATION FOR EXAMINING THE PRINCIPAL CHARACTERISTICS AND PERFORMANCE OF SMALL SWATH SHIPS. DISPLACEMENTS OF THE FOUR BASELINE SWATH CONCEPTS WERE CHOSEN TO BRACKET EXISTING COAST GUARD PATROL VESSELS. IN DEVELOPING THE FOUR BASELINE CONCEPTS, IT WAS ASSUMED THAT DISPLACEMENTS WOULD REMAIN FIXED. FOR EACH OF THESE CONCEPTS, THE PARAMETERS OF INTEREST WERE GROSS GEOMETRY: AREA AND VOLUME CHARACTERISTICS: WEIGHT GROUP DISTRIBUTION: SPEED, ENDURANCE AND RANGE TRADE-OFFS OF THE SMALL SWATH CONCEPTS DEVELOPED. THIS REPORT DOCUMENTS THE DEVELOPMENT OF THE FOUR CONCEPTS, THE TRADE-OFFS, AND PERFORMANCE EVALUATIONS PERFORMED. FROM THIS FOUNDATION, GENERAL TRENDS OF SMALL SWATH SHIP CHARACTERISTICS ARE DEVELOPED.

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NOMENCLATURE

BHP	Brake horsepower
BOA	Beam, overall
CODAD	Combined Diesel And Diesel propulsion system
CODAG	Combined Diesel And Gas turbine propulsion system
Cp	Prismatic Coefficient
CPIC	Coastal Patrol and Interdiction Craft - a planing boat
CPO	Chief Petty Officer
CRP	Controllable, Reversible Pitch propellers
CVS	Commercial Vessel Safety
Cwp	Waterplane Coefficient
DIAmax	Maximum Diameter of the lower hull
DRAFTmax	Maximum Draft of the ship
DTNSRDC	David Taylor Naval Ship R & D Center
EAR	Expanded Area Ratio
EHP	Effective Horsepower
ELT	Enforcement of Laws and Treaties
GML	Longitudinal Metacentric height
GMT	Transverse Metacentric height
HH-65A	DOLPHIN helicopter, currently under consideration by USCG
HVAC	Heating, Ventilation and Air-Conditioning
H1/3	Significant Wave Height
KG	Vertical Center of Gravity from Keel
kW	Kilowatts
LBP	Length Between Perpendiculars

LCB	Longitudinal Center of Buoyancy
LCF	Longitudinal Center of Flotation
LCG	Longitudinal Center of Gravity
Llower hull	Length of the lower hull
LOA	Length, overall
Lstrut	Length of the strut
LTON	Long tons
LWL	Length along the waterline
MEP	Marine Environment Protection
MSA	Marine Science Activities
NAVSEA	Naval Sea Systems Command
nmi	Nautical miles
NOSC	Naval Ocean Systems Center, formerly NUC
NUC	Naval Undersea Center
PC	Propulsive Coefficient
psi	Pounds per square inch
PSS	Port Safety and Security
RBS	Recreational Boating Safety
RMS	Root Mean Square
RPM	Revolutions per minute
RUWS	Remote Underwater Work Station
SAR	Search and Rescue
sfc	Specific fuel consumption
SH-2F	USN LAMPS I helicopter
SHP	Shaft Horsepower
SRA	Short Range Aids to Navigation
SSP	Semi-Submerged Platform KAIMALINO

TPI	Tons per Inch immersion
tstrut	Maximum strut thickness
USCG	United States Coast Guard
USN	United States Navy
WHEC	High Endurance Cutter
WMEC	Medium Endurance Cutter
WPA	Waterplane Area
WPB	Patrol Boat
WPC	Patrol Craft
∇	Displaced Volume
$H1/3/\nabla 1/3$	Significant Wave Height/Displaced Volume

ABSTRACT

As part of an effort to examine advanced vehicles configured for United States Coast Guard (USCG) missions, the Coast Guard Marine Vehicle Technology Branch, Office of Research and Development, tasked the SWATH Project Office at the David Taylor Naval Ship Research and Development Center to perform a study examining the applicability of the SWATH concept to these missions. The approach taken in performing this study was to develop four SWATH concepts configured for Coast Guard missions and use these four concepts as a foundation for examining the principal characteristics and performance of small SWATH ships. Displacements of the four baseline SWATH concepts were chosen to bracket existing Coast Guard patrol vessels. In developing the four baseline concepts, it was assumed that displacements would remain fixed. For each of these concepts, the parameters of interest were gross geometry; area and volume characteristics; weight group distribution; speed, endurance and range trade-offs of the small SWATH concepts developed. This report documents the development of the four concepts, the trade-offs, and performance evaluations performed. From this foundation, general trends of small SWATH ship characteristics are developed.

ADMINISTRATIVE INFORMATION

The work described in this report was performed by the SWATH Ship Development Office (Code 1110) of the David Taylor Naval Ship R & D Center. Funding for this work was provided by the United States Coast Guard Marine Vehicle Technology Branch, Office of Research and Development, through USCG Military Industrial Work Request (MIPR) number Z-70099-4097 of 18 June 1981.

INVESTIGATION OF THE CHARACTERISTICS OF SMALL SWATH SHIPS CONFIGURED FOR US COAST GUARD MISSIONS

BACKGROUND

The SWATH Ship Development Office at the David Taylor Naval Ship Research and Development Center (DTNSRDC) was tasked to perform a parametric study on small waterplane area twin hull (SWATH) ships configured for the United States Coast Guard (USCG) missions. The objective of this study, as stated in Reference 1, was:

> "To develop a matrix of "notional" SWATH characteristics which match or bracket the designated characteristics of existing and programmed USCG vessel classes. The principal characteristics of interest are displacement, speed, endurance/range, fixed and disposable payloads and seakeeping. The major problem to be addressed in this analysis is to investigate qualitative and quantitative relationships between these principal vessel characteristics as performance and size parameters are varied."

The general approach in performing this study consisted basically of three stages: Task I was to gather from the USCG and other sources,

available data on existing USCG vessels and mission requirements; Task II was to develop four baseline concepts, to perform the parametric study, and to examine the performance of SWATH ships in USCG roles; and Task III was to prepare conceptual outboard arrangements and document the study for publication. Prior to beginning the parametric study, the existing DTNSRDC SWATH concept data base (including existing ships, model tests and previous feasibility studies) was compared with existing USCG ships. This is shown in Figure 1, where the decision to focus attention on five sizes (125, 250, 750, 1250, and 1750 LTON) is illustrated.

INTRODUCTION

The basic theory underlying the SWATH concept is as follows: place most of the buoyant volume well below the sea surface and most of the usable volume well above the sea surface, and connect the two with the minimum reasonable volume. The result is a twin hull ship characterized by a relatively large beam and having small waterplane area struts. These two factors provide the SWATH ship with some key advantages over conventional monohulls. First, the amplitude of a ship's motion is greatly affected by wave exciting forces which, to the first order, are proportional to its waterplane area. Therefore, a small waterplane area results in small ship motions in a seaway. Secondly, due to their configuration, SWATH ships can be designed to have larger deck areas than monohulls of similar displacement, thereby enhancing

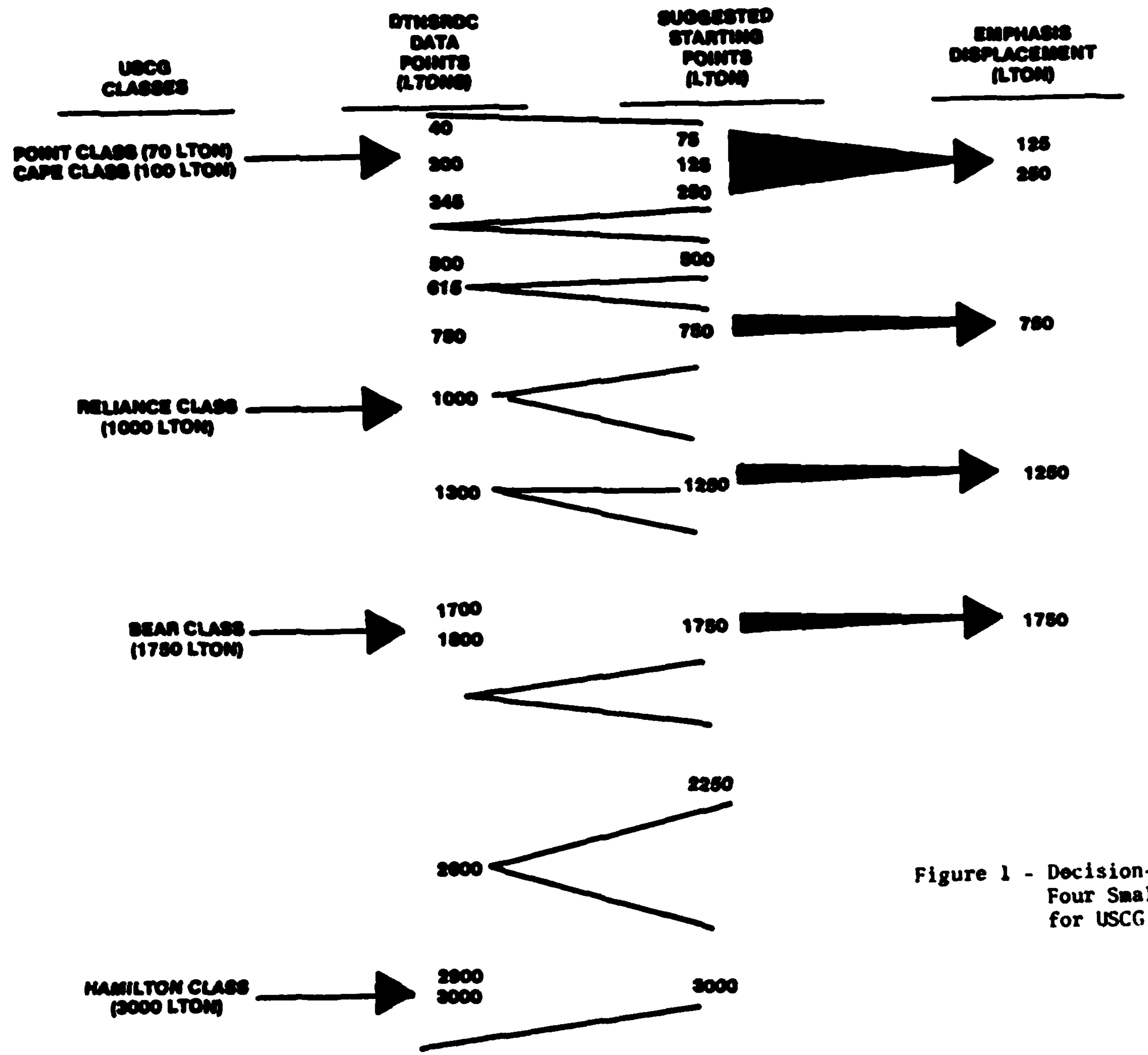


Figure 1 - Decision-Making Flowchart for Four Small SWATH Ships Configured for USCG Missions

the operational flexibility of the ship.

This large deck area enables suitably sized helicopter landing pads to be placed on relatively small SWATH ships, while providing space for other equipment required for a multimission, operationally flexible ship. Due to the superior seakeeping of SWATH ships, helicopter operations may be carried out in heavy seas to the point of helicopter wind-over-deck limitations, instead of ship motion limitations.

The improved operational capability of the SWATH concept is obtained at some cost. The key costs being the increased sensitivity of the ship to changes in load resulting from the small waterplane area, and a reduced payload/fuel carrying capacity, as a percentage of nominal full load displacement, due to a larger structural weight fraction. A SWATH ship will usually have a somewhat larger draft as well, but that may not always be a disadvantage since propeller performance is improved.

Figure 2 shows the basic components of a SWATH ship which will be referred to throughout this report. An excellent reference concerning most aspects of the SWATH concept but concentrating on larger displacements (frigate sizes) is Reference 2.

USCG MISSIONS AND MISSION REQUIREMENTS

During peacetime, the principal missions of the USCG are Enforcement of Laws and Treaties (ELT) and Search and Rescue (SAR). The ELT missions [3, 4, 5] include such tasks as: patrol; intelligence gathering

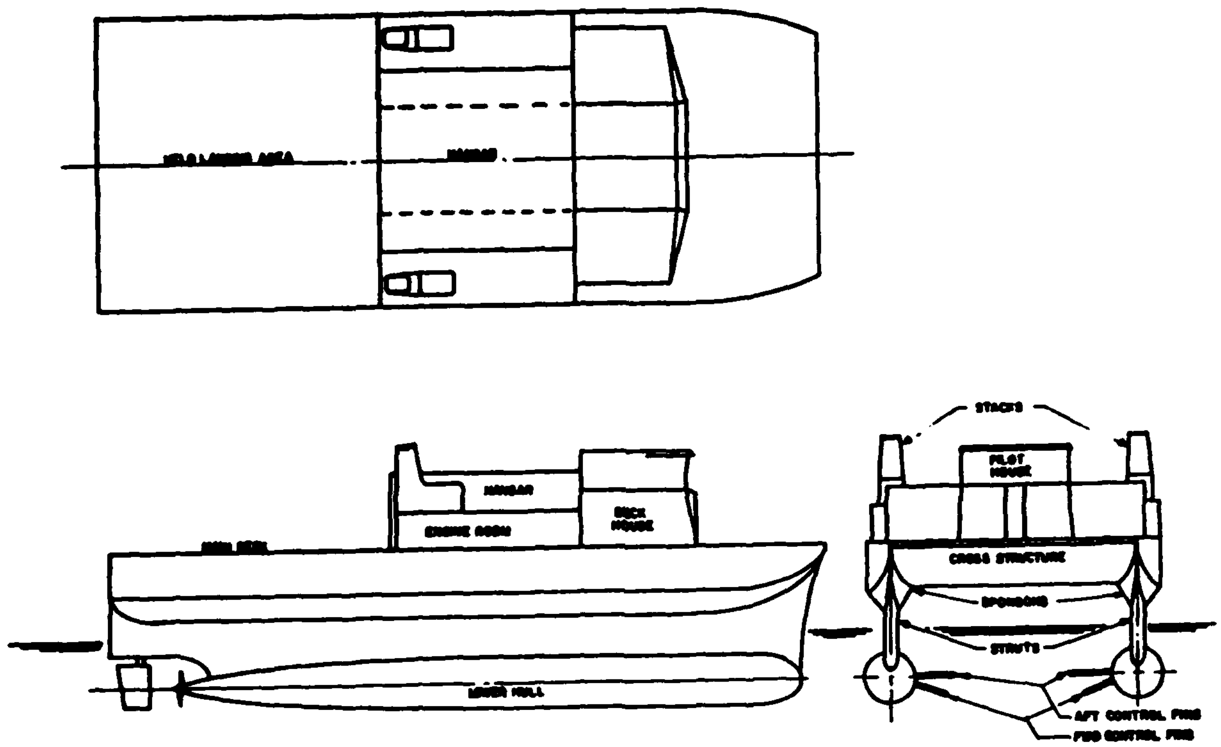


Figure 2 - SWATH Ship Features

hot pursuit; boarding and searching for smuggling and drugs; boarding and inspection of fishing vessels, both foreign and domestic; and enforcement of any laws pertaining to ocean resources protection and conservation. The SAR mission includes such tasks as: conducting and coordinating sea searches; fire fighting; dewatering damaged vessels; and towing damaged or disabled ships. Some of the other peacetime missions of the USCG are as follows: Short Range Aids to Navigation (SRA), including fuel and liquids transport and placement and removal of temporary hazard markings; Commercial Vessel Safety (CVS), including escort of carriers of hazardous cargoes; Marine Environmental Protection (MEP), including quick reaction to oil spills and deployment of containment gear; Marine Science Activities (MSA); Port Safety and Security (PSS) and; Recreational Boating Safety (RBS).

In the event of war, it is expected that the USCG may be called upon to supplement the USN in performing military operations. Some of the missions the USCG might be expected to perform [3-7] are as follows: mine countermeasures, including mine hunting and mine neutralization; remote vehicle support; shallow water antisubmarine warfare; hydrographic survey and bottom mapping; convoying within the 200 nmi economic zone; radar and communication pickets; intelligence gathering; and inshore defense and interdiction.

After consideration of the anticipated USCG mission needs, a general set of mission requirements to be met by the SWATH concepts developed for the parametric study was evolved, based primarily on References 3 and 8. The ELT mission was to be the primary mission for the USCG

SWATH concepts and the missions of SAR, CVS, MSA, MEP, and military operations were to be treated as secondary missions. It was desired that each concept, taking relative size into account, be evaluated for its ability to perform the following tasks:

1. Multimission capability for a mission endurance of five or more days;

2. Intercept, overtake, and maintain hot pursuit of waterborne craft for at least 24 hours, with a maximum speed at least 24 knots;

3. Provide boarding capability and a 3 to 5 person prize crew;

4. Carry armament necessary to implement the ELT mission, as well as space and weight reservation for additional armament in the event of war;

5. Provide capability for communication with Department of Defense vessels as well as commercial ships, aircraft, and shore facilities;

6. Perform search and rescue tasks;

7. Tow vessels of up to 500 LTON in displacement at a minimum speed of 5 knots;

8. Fight fires aboard and dewater other vessels;

9. Carry out missions in a Sea State 5, operate in a reduced mode in a Sea State 6, and survive in a Sea State 7;

10. Meet two compartment flooding criteria;

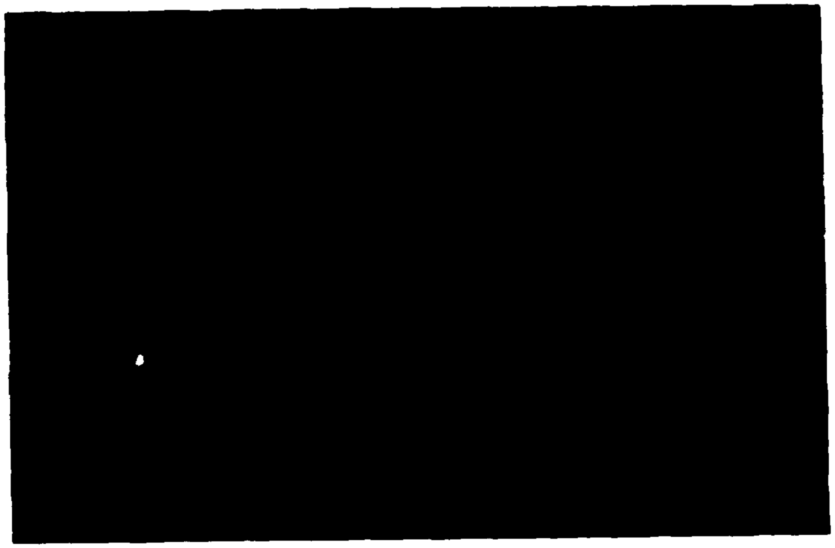
11. Provide habitability standards equal to or better than those on existing USCG vessels;

12. Provide helicopter capability.

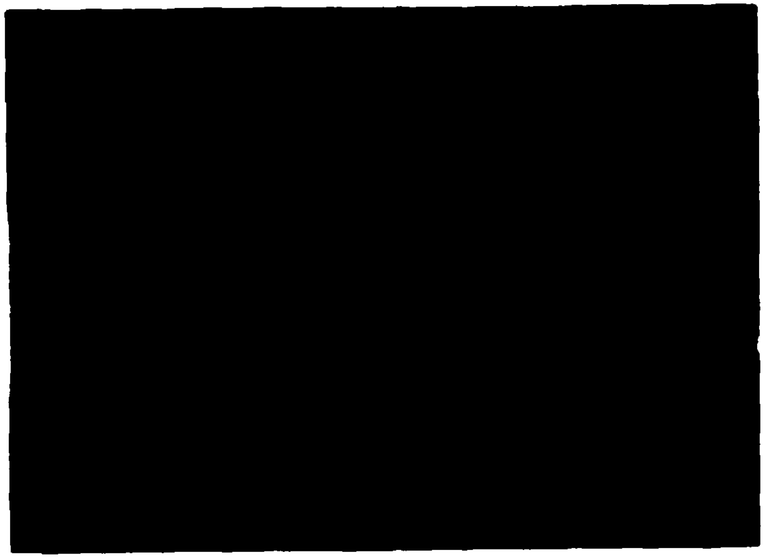
Several of the above mentioned tasks impose strict requirements on ship performance particularly in areas such as deck steadiness, low speed coursekeeping and maneuverability, station-keeping and mission duration. Ships well adapted to offshore and coastal work are necessary to satisfy these mission needs. The SWATH concept, as demonstrated by existing SWATH ships, offers the potential for accomplishing these missions.

OPERATIONAL CAPABILITY OF EXISTING SWATH SHIPS

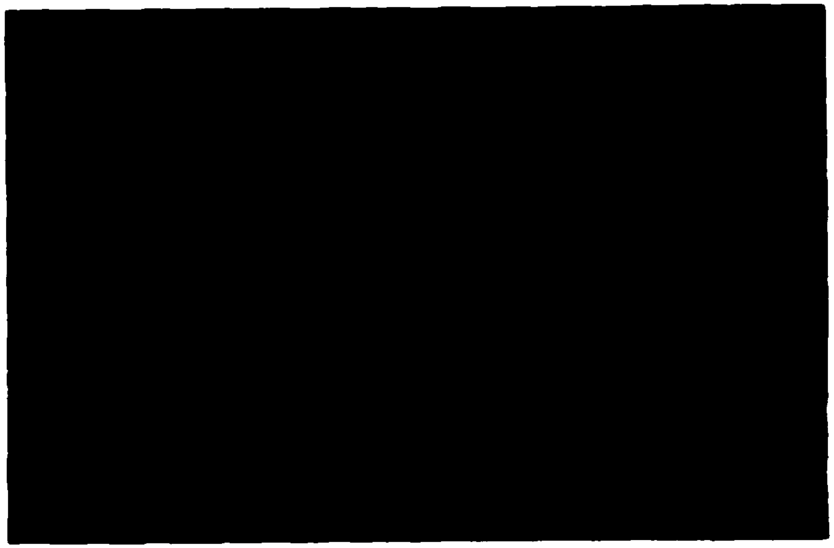
The SWATH concept is not new, having been under development by the USN since 1970. However, to the best knowledge of the authors, as of 1982, only five operational SWATH ships have been built in the world. In the United States there are the SSP KAIMALINO, a USN work boat displacing 220 LTON and the SUAVE LINO, a privately owned fishing boat displacing 50 LTON. The remaining three are in Japan: Mitsui Shipbuilding and Engineering has built the MESA 80 (now called the SEA GULL), a 402 passenger ferry boat displacing approximately 345 LTON and the KOTOZAKI, a hydrographic survey vessel displacing about 250 LTON. Mitsubishi Shipbuilding has also built a hydrographic survey vessel named the OHTORI which displaces approximately 250 LTON. The SUAVE LINO, SSP KAIMALINO, and MESA 80 are of principal interest for this parametric study and are presented, along with a table of characteristics, in Figure 3.



SSP KAIMALINO



MESA 80



SUAVE LINO

	MESA 80	KAIMALINO	SUAVE LINO
FULL LOAD DISP (LTON)	345	220	52
OVERALL LENGTH (ft)	109.5	87.8	62.9
LBP (ft)	106.0	77.0	54.1
OVERALL BEAM (ft)	53	45	30
MAXIMUM DRAFT (ft)	10.3	15.3	7.0
CLEARANCE (ft)	8	4.9	2
INSTALLED SHP (hp)	8100	4500	850
DRIVE SYSTEM	Z DRIVE, DUAL SHAFT	Z DRIVE, CHAIN	Z DRIVE, SINGLE SHAFT
MAXIMUM SPEED (Kts)	27.1	18	18
CONSTRUCTION MATERIAL	ALL ALUMINUM	STEEL STRUTS & HULLS, ALUMINUM BOX	ALL ALUMINUM

Figure 3 - Existing SWATH Ships and Their Characteristics

The SSP, MESA 80, and SUAVE LINO have frequently demonstrated the applicability of the SWATH configuration to USCG-type missions and operations. Tests and trials which have been performed on each craft have been used to validate existing SWATH ship analytics and operational capabilities. Because these ships have demonstrated the type of operations of interest, they were used in this study as the basis for the concepts developed. Some of the more important operational trials performed on each of these SWATH ships are described in the following paragraphs.

The SSP KAIMALINO was built at the USCG Shipyard at Curtis Bay, Maryland in 1972-73 as a work boat for the Naval Ocean Systems Center (NOSC), [9]. Originally, the SSP displaced 190 LTON, but was later modified to 220 LTON to increase its payload capacity by the addition of fiberglass covered foam buoyancy blisters, [10]. Since 1975, the SSP has been operating in the frequently rough waters of Hawaii and has logged more than 5000 hours performing experimental operations and range work for the USN.

Of the many trials performed on the SSP, [10-18], one of the most illustrative was a side-by-side seakeeping comparison with two USCG ships. The main intent of the trial performed in 1978, [11,12], was to measure and record the effect of ship motions on the crew and their performance. The three ships involved in the test are shown in Figure 4: the largest ship being the MELLON, a 3000 LTON High Endurance Cutter (WHEC); the next ship is the 220 LTON SSP KAIMALINO; and the third, the 100 LTON Patrol Boat (WPB), the CAPE CORWIN. Figure 5 shows some

Figure 4 - WHEC MELLON, SSP KAIMALINO, and CAPE CORWIN

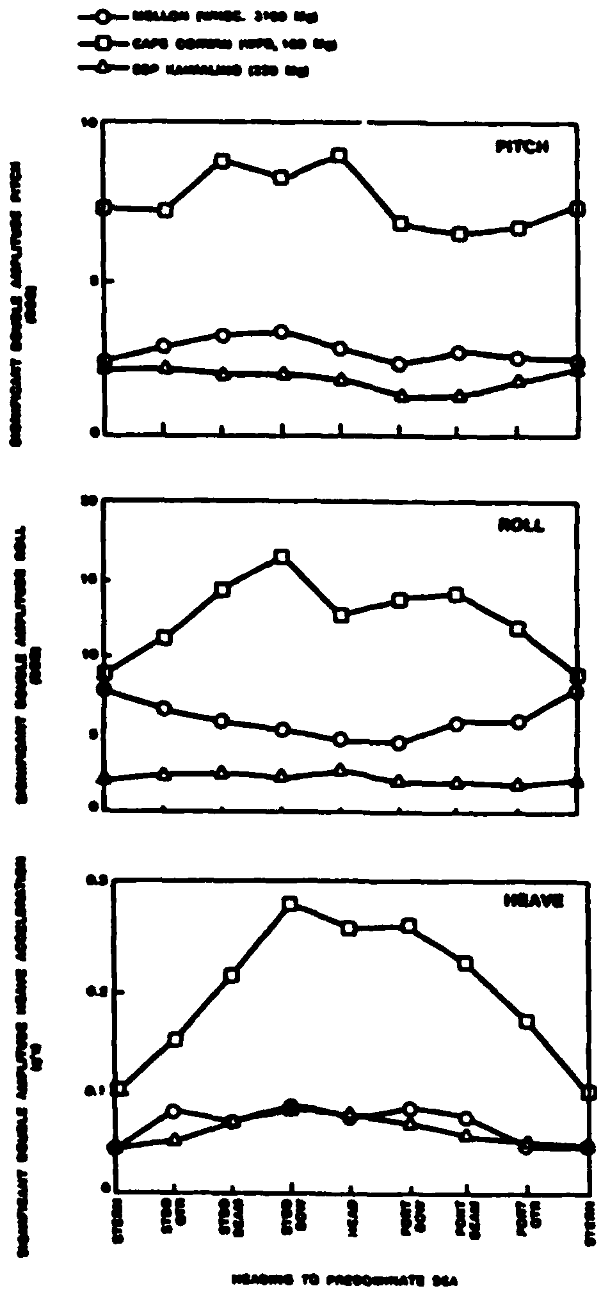


Figure 5 - Comparison of Motion of the
SSP KAIMALINO with USCG Monohulls

of the motion results as a function of heading. As can be seen, the motions of the 220 LTON SSP are comparable to or better than those of the 3000 LTON monohull, which are, in turn, considerably better than those of the 100 LTON monohull. The exception is in the case of roll where the SSP has substantially better roll characteristics than those of either monohull, at all headings.

In 1976, a trial was performed on the SSP which demonstrated the compatibility of the SWATH concept with helicopter operations, [13-14]. As a result of this trial, the then 190-LTON SSP KAIMALINO was the smallest ship in the USN certified for full daylight operations with the SH-2F LAMPS I helicopter. During the same period, compatibility trials with the USCG helicopter, the HH-52, were also conducted. Over 80 landings and take-offs were performed in seas ranging from calm to Sea State 4 (significant wave heights of 0 to 7 ft). In fact, one landing took place in Sea State 3, with the SSP dead in the water. Pilots' reaction to landing on the SSP are summarized by the following statements from Reference 13:

> "The minimal deck motion observed while on approach and landing simplified the task tremendously;"
>
> "The motion of the SSP in heavy seas was comparable to the effects of relatively calm seas on current LAMPS ships."

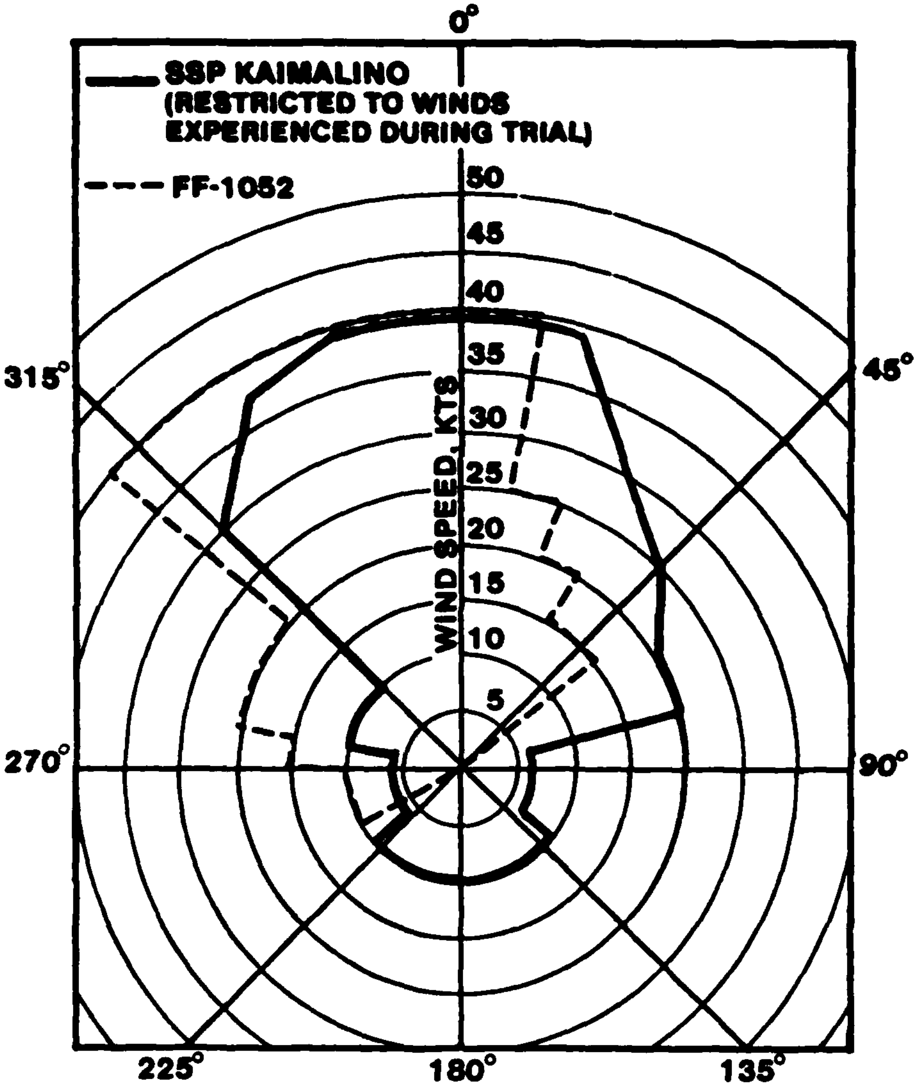
The latter statement was in reference to the FF 1052 Class frigates which displace about 4100 LTON. A comparison of the land/launch envelopes of the 1052 class and the SSP and the rotor engage/disengage envelopes of the SH-2F helicopter on land and on the SSP were made in

Reference 14 and are presented in Figure 6. As can be seen, the land/launch envelope of the SSP is roughly the same area and coverage as that of the FF 1052. The rotor engage/disengage envelope of the SH-2F on land is somewhat larger than that for the SSP, but it should be noted that the SSP envelope was limited to only the winds experienced during the trial period. Based on this data, it would appear that small SWATH ships offer considerable promise in handling helicopters.

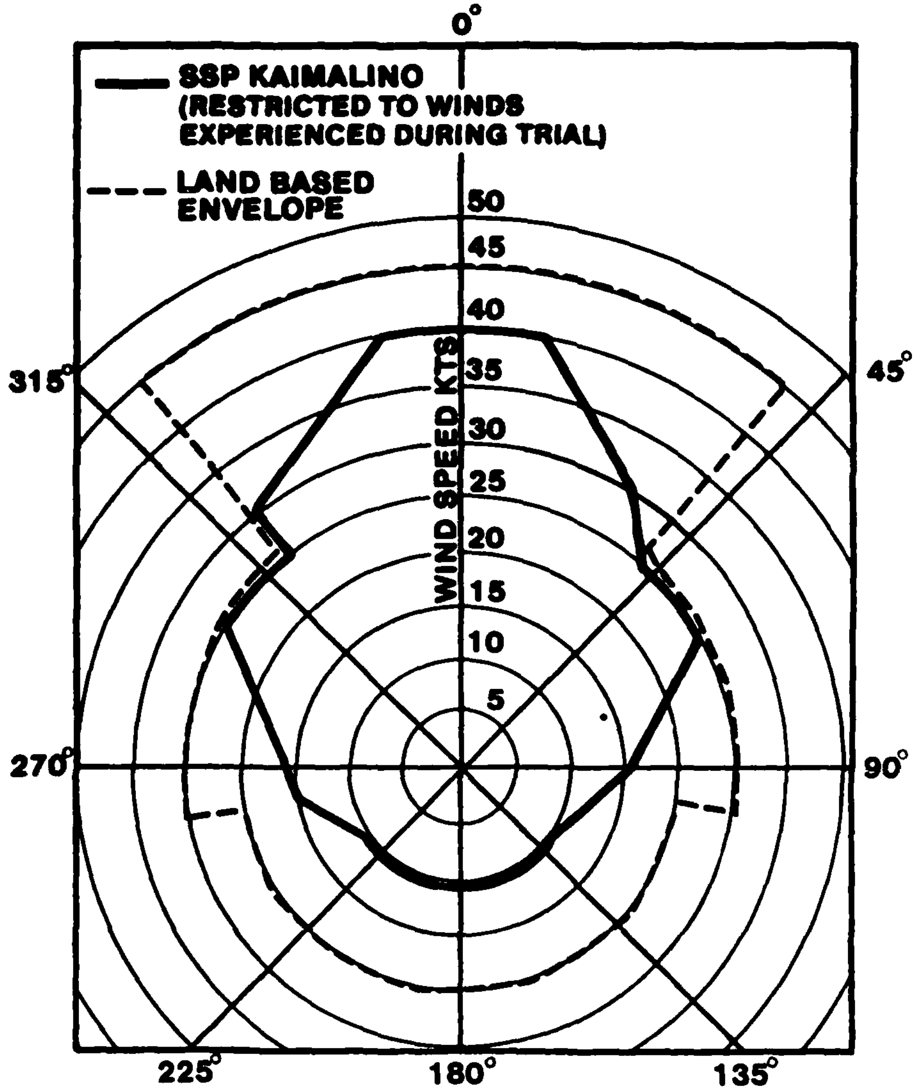
Also in 1976, the SSP was used as the support ship for a remotely piloted vehicle demonstration, using the Remote Underwater Work System (RUWS). The SSP demonstrated the ability to precisely follow the RUWS for several hours, then keep station for several hours, independent of seaway direction. The SSP has proven the compatibility of the SWATH concept with over-the-side and through-a-well launch and recovery as demonstrated by its frequent recovery of mine hunting gear, RUWS, wave-rider buoys, test gear, and its own Zodiac boat.

In 1978, turning trials were performed on the SSP, [15]. The results of these trials showed the SSP had a turning diameter of roughly six ship lengths when there was induced roll in the turn at 16 knots. This would be comparable to 3-4 ship lengths for a monohull, since SWATH ships usually have shorter hull lengths than most monohulls of comparable displacement. Reference 15 concluded, in part, that smaller turning diameters may be possible at higher speeds. Additional seakeeping tests have been performed on the SSP and are documented in References 16 and 17. Finally, a structural model validation test performed on the SSP is documented in Reference 18.

Figure 6 - **COMPARISONS ILLUSTRATING THE HELICOPTER COMPATABILITY OF THE SSP KAIMALINO**



SH-2F HELICOPTER LAND/LAUNCH ENVELOPE (STARBOARD APPROACH)



SH-2F HELICOPTER ROTOR ENGAGE/DISENGAGE ENVELOPE

The MESA 80 is the second SWATH shown in Figure 3. It was launched in 1979, trialed in 1980, and is now serving as a commercial ferry named the SEA GULL), [19-21]. Of all aluminum construction, the MESA 80 displaces approximately 345 LTON. During an extensive trial period, the MESA 80 demonstrated a top speed of 27.1 knots. It was designed for and operates at a cruise speed of 24.1 knots. The MESA 80 also underwent seakeeping trials in Sea States 3 and 4, showing a total speed loss in a high Sea State 4, of less than two percent. It has been reported [19] that in a sea with waveheights of 10 to 15 ft, there were no excessive wave impacts on the underside of the cross-structure.

The most recent SWATH ship to be constructed in the United States is the privately owned SUAVE LINO, launched in 1981. Designed as a private fishing boat, the SUAVE LINO displaces approximately 50 LTON and is of all aluminum construction. Recently, while under lease to the USN, the SUAVE LINO underwent extensive trials, under both USN and USCG sponsorship, including powering, performance, structural and operational trials, [22]. Results from all trials have contributed to validation of existing theory and in proving operational utility. Coursekeeping trials on both one propeller and two propellers have been performed, demonstrating the capability of maintaining a heading under both a two propeller condition and a one propeller condition, with small rudder deflection.

Severa' operational trials have also been performed on the SUAVE LINO, including such operations as diver support, towing, boat launch and recovery, and hydrographic survey and bottom mapping with a towed

sonar. Towing tests consisted of the SUAVE LINO towing a USCG 82 ft WPB, displacing 65 LTON and, conversely, the WPB towing the SUAVE LINO. There was no apparent sinkage or trim while the SUAVE LINO was towing the WPB and no apparent instabilities while the SUAVE LINO was under tow.

In rough water operations, the SUAVE LINO has performed exceptionally well. Recently, the 50-LTON boat operated in head and following seas of 10 to 12 ft without major problems. Although there was considerable slamming, the result of the impacts did not appear to be severe or pose major problems. Onboard observers have been impressd with its behavior, including its motions in following seas.

THE PARAMETRIC STUDY

It was decided that the parametric study would be developed around four SWATH concepts configured for the USCG missions and mission requirements described previously. After discussions with the USCG, the sizes of the four basic concepts were decided to be 125, 250, 750, and 1250 LTON. The 125-LTON size was selected to represent a small SWATH WPB with capabilities similar to the existing WPB classes. The 250-LTON concept was selected as an estimate of the smallest size SWATH ship to have helicopter capability. The 750-LTON concept was selected to represent a Medium Endurance Cutter (WMEC)-type ship with complete helicopter capability, and the 1250-LTON concept was selected to represent a ship at the upper end of the WMEC-type classes.

These four concepts formed the basis of the parametric study but by no means the extent of the study. Analytic predictions were made in areas such as resistance, powering, and seakeeping for concepts up to 3000 LTON in size. However, at the direction of the USCG, the predominant amount of the data that will be presented in the remainder of this report are for concepts in the range of 50 to 1250 LTON.

GEOMETRY INITIALIZATION

The first step in developing these four concepts was to determine their general configuration. SWATH ship geometry initialization is an iterative process which balances resistance and powering characteristics with seakeeping performance, structural weight, arrangement and volume considerations, and hydrostatic properties. Though similar in nature to conventional monohull design, the process is, in fact, very different since the designer has considerably more latitude on which generic characteristics he wishes to emphasize. This inherent latitude leads to a concept which is "tunable" to a greater degree than monohulls. For instance, a SWATH ship configured for a high speed mission will not have the same configuration, i.e., the same distribution of waterplane area or underwater volume as a SWATH ship configured for slower speed missions. Further, SWATH ships have many more parameters that can be varied, and are sensitive to many more parameters than are monohulls. Often these parameters have diametrically opposite effects on the total ship system performance. The SWATH ship design then becomes

a process of compromising overall performance characteristics to produce a ship system which can satisfactorily perform a given mission. Because there is so little existing SWATH ship detail design data, SWATH ship design, at this time, is less straightforward than modern monohull design. At this point in time, for a given SWATH ship design, most of the parameters affecting the ship characteristics must be examined for each new application because the existing data base is too limited for a priori selection of ship geometry from mission requirements. This lends additional importance to the specification of operational requirements, so that the SWATH ship can be properly "tuned" or configured.

Based on the mission requirements and needs described previously, several goals and assumptions were established to guide the geometry initialization process:

1. Provide helicopter capability, if at all possible;

2. Fuel economy would be considered most important;

3. The resistance characteristics would be optimized for cruise speeds of 10-15 knots and maximum speeds of between 25-30 knots;

4. Seakeeping would be considered next in importance;

5. Utilize a configuration which has no underwater portion extending beyond the envelope defined by the above water portion of the ship;

6. Reduce structural weight where possible;

7. Minimimize draft;

8. Utilize a configuration that places the rudder in the wake of the propeller to improve maneuvering;

9. A simple hull form (as opposed to contoured) would be used

for ease of construction.

It should be noted that point 5 could have a substantial impact on the configuration and size of any concept designed with that criterion. Point 5 is felt to be particularly important in this study because of the operational aspects of the individual USCG missions. Several of these missions require coming alongside other vessels and piers and over-the-side work, all of which would be made substantially more difficult by the presence of unseen underwater portions of the ship. In addition, to satisfy both points 5 and 7, configurations with struts extending beyond the lower hulls at the stern (overhanging struts) were considered. All existing SWATH ships, including those used as the baseline configurations for this study, are configured in this manner. A cursory examination of the effect of contouring the lower hulls on the resistance and powering characteristics of small SWATH ships was performed. The results indicated that in the small size, high Froude number regime of interest in this report, the resistance benefits were of insufficient magnitude to waive constraint 9. Additional work may result in somewhat improved resistance characteristics of small SWATH ships. The authors, therefore, chose to consider only simple lower hull forms in this report for construction simplicity and lower construction cost.

In determining the basic configuration of a SWATH concept, it has proven wise to start with a form for which hard data is available, either by model test or by full-scale data. For this study, the MESA 80 and SUAVE LINO were used as starting points. Each configuration was scaled

(by geosim) to the desired displacement, modified to meet the main deck arrangement considerations (particularly length) of the particular craft, if necessary, and compared on the basis of resistance characteristics. The most promising baseline form was then optimized around the desired length and the specified speed characteristics, as defined in point 3 above. The hydrostatics of the baseline configuration were then checked to ensure a practical ship, and the structural weight of the concept was estimated. Finally the seakeeping characteristics were examined. For the cases examined herein, the deck area and enclosed volume of the concept were allowed to "fall out" of the geometry initialization. For other SWATH ship designs for which volume and deck area considerations play a more important role, the SWATH concept can be optimized for internal volume or usable deck area earlier in the geometry initialization stage. In each phase of the geometry initialization the baseline form was altered to improve the various characteristics being examined, thus compromising some of the other properties of the concept. The resulting configuration, hopefully, is a well balanced baseline which reflects the governing design philosophy.

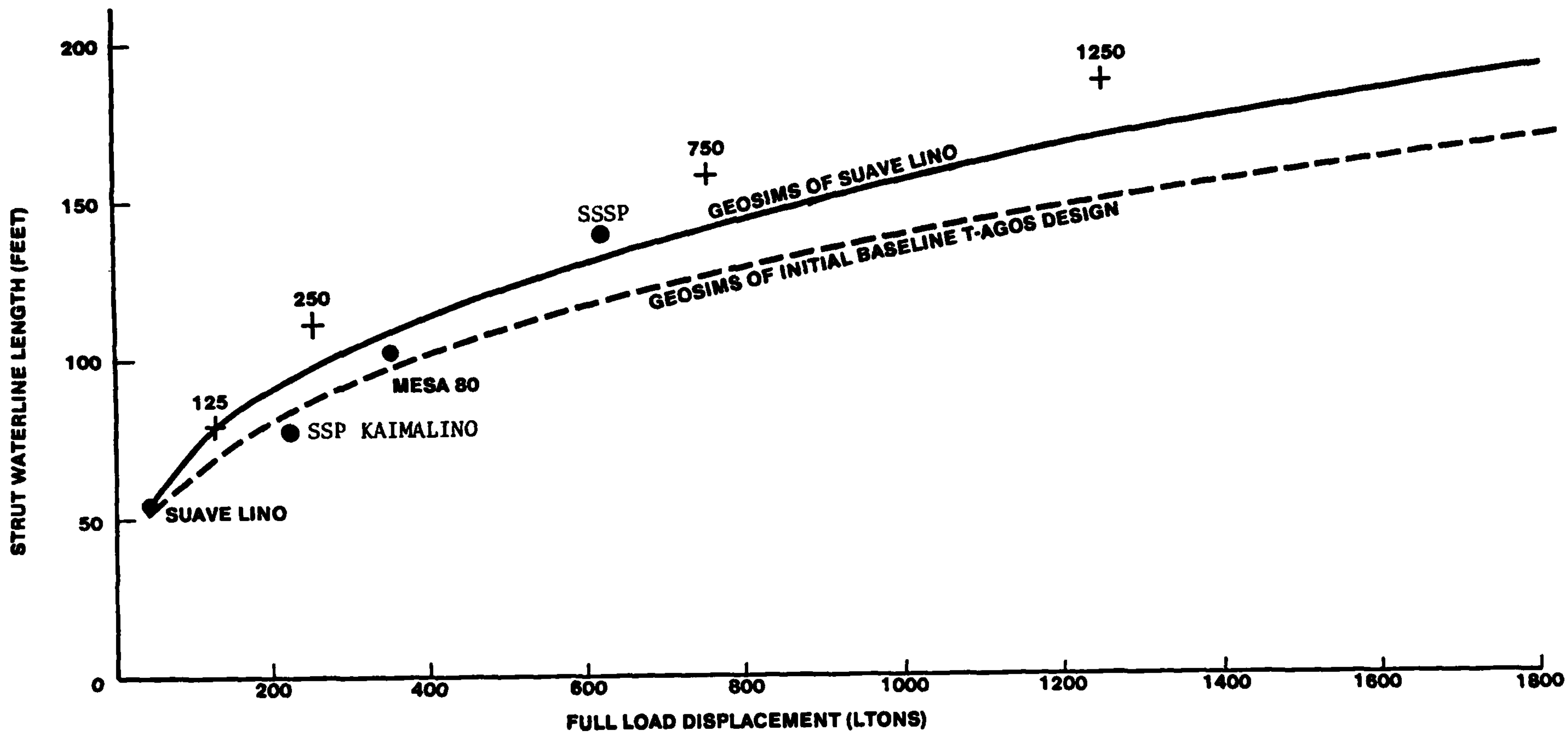
As noted in point 2 above, fuel economy was a key factor in the configuring of the USCG concepts, so particular attention was given to the parameters with the greatest effect on the resistance and propulsion characteristics of each concept. Predominate among these factors is the ship length and the distribution of the buoyancy and waterplane area (WPA) of the concept. From a number of undocumented SWATH resistance and propulsion parametric studies, it appears that a wide separation

of the longitudinal center of flotation (LCF) and the longitudinal center of buoyancy (LCB) is desireable. Secondary factors to be considered with respect to the propulsion characteristics of a SWATH ship are local geometric features such as strut setback and the design of the propeller cutout.

The nature of the USCG missions require good low speed seakeeping properties, as well as good fuel economy characteristics. In SWATH ships, good low speed seakeeping performance is a direct function of WPA and the longitudinal metacentric height (GML), both of which are quite sensitive to the waterline length (LWL). Figures 7 and 8 show the LWL and WPA of the four conceptual ships. Also shown are curves derived by geosimming the hull configurations of the SUAVE LINO, and the 3000 LTON T-AGOS, [23], both of which have proven to be excellent low speed seakeeping forms. Full-scale data points, and points representing the four concepts developed herein, and the 614 LTON Stretched SSP (SSSP) model, [24], have also been included.

As is shown in Figure 7, the LWL of the three larger concepts are longer than geosims of the SUAVE LINO or the T-AGOS. This is due to the helicopter deck length requirements and results in a higher GML, which, in turn, results in somewhat degraded low speed seakeeping properties, particularly in high encounter frequency situations. Figure 8 shows that the WPAs of the four concepts are consistent with those of the SUAVE LINO and smaller than those of the T-AGOS geosims. According to References 25 and 26, which document two analytic, parametric studies on the effect of several parameters on SWATH seakeeping, the high GML

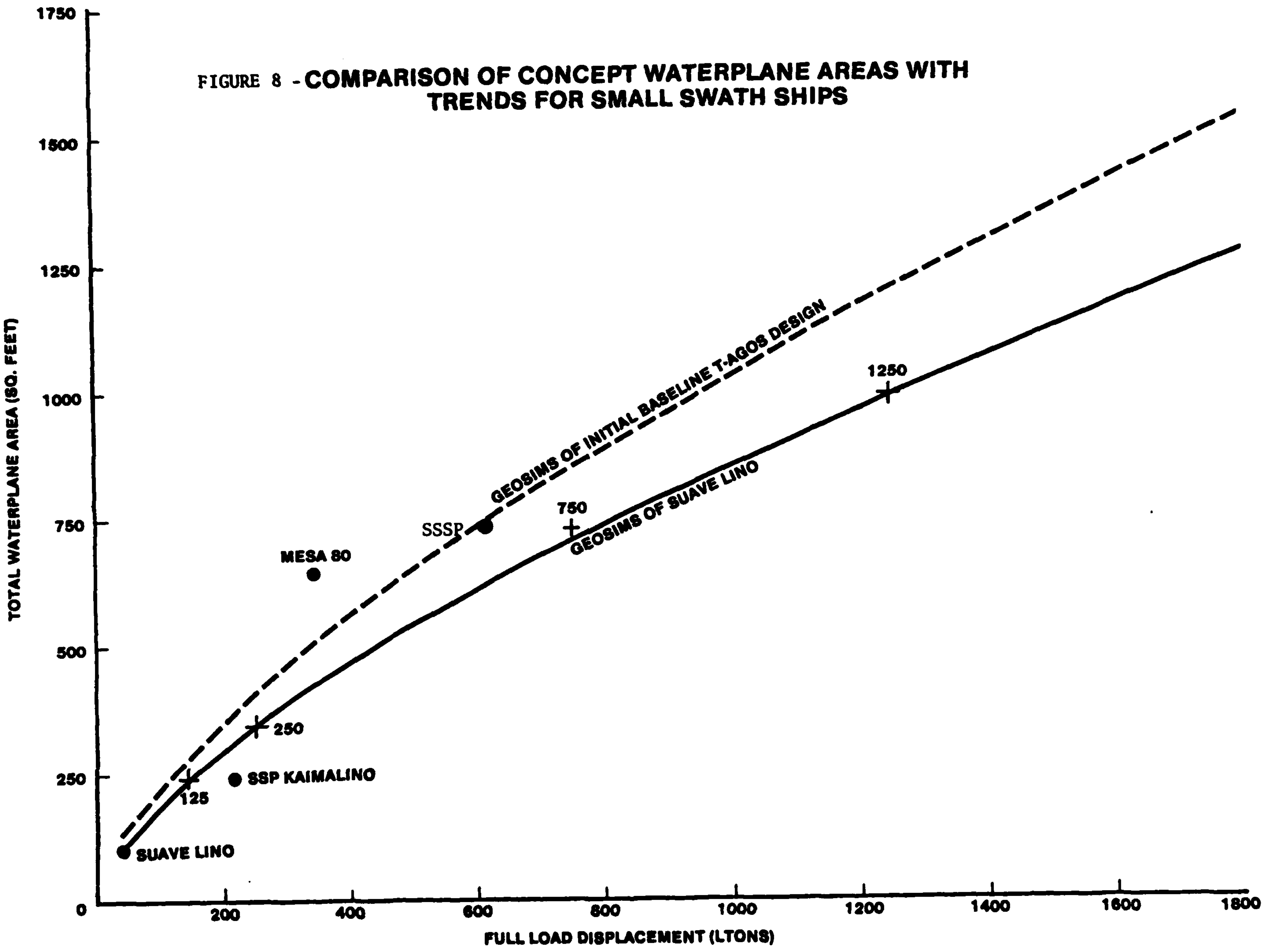
FIGURE 7 - **COMPARISON OF CONCEPT WATERLINE LENGTHS WITH TRENDS FOR SMALL SWATH SHIPS**



of the four concepts should result in somewhat higher bow motions, but increased pitch stability, particularly in following seas. The relative locations of the LCB and the LCF in a SWATH ship are also important parameters to consider when examining SWATH ship seakeeping. In all four cases examined here, the LCF is somewhat aft of LCB. In general, according to Reference 25, an LCF location aft of LCB has been found to reduce bow motions, relative to the water, in head seas and increase relative bow motions in following seas. Thus, the effect of high GML may be partially offset by the effect of LCB/LCF separation.

The transverse spacing between strut centerlines for a SWATH ship is governed by the desired WPA, the vertical center of gravity (VCG) and the desired amount of transverse metacentric height (GMT), and is the key factor in the roll and transverse stability of the concept. The GMT of a SWATH ship is proportional to the WPA times the square of the strut spacing. For the analyses performed, the VCG was assumed to be located at the bottom of the cross-structure. The most effective method of changing the GMT of a SWATH concept is an alteration to the strut separation. For instance, a 6 ft (18%) reduction in the beam of the 125 LTON concept would result in about a 5 ft reduction in the GMT without a major impact on the rest of the ship system. This same change in GMT can be attained by decreasing the WPA by 30% which may have a major impact of such ship properties as TPI, resistance, propulsion and seakeeping. The beam of the concepts examined herein were chosen on the basis of the desired GMT.

FIGURE 8 - COMPARISON OF CONCEPT WATERPLANE AREAS WITH TRENDS FOR SMALL SWATH SHIPS



The results of the seakeeping analysis performed on each of the four concepts are presented later in this report under the heading "Seakeeping Performance." As shown in the preceding discussion, the desired parameters for good powering characteristics are often opposite the desired parameters for a good seakeeping form. The geometry initialization process therefore is an attempt to compromise the various parameters to produce a satisfactory hull form that reflects the design philosophy of a given application. In general, SWATH seakeeping characteristics are so much better than those of monohulls, that improvement in resistance characteristics is often made with small cost to seakeeping, which is often a good trade-off.

Since, at this time, no two SWATH concepts are designed in the same manner, and the existing SWATH data base is so small, it is difficult to generalize the geometry initialization process. In a an attempt to illustrate the process, an example is presented, representative of the design approach used for this study. For the 125 LTON concept, the lower hulls and struts of the MESA 80 and SUAVE LINO were geosimmed from their respective displacements to 125 LTON and then compared on the basis of residuary resistance (primarily the wave drag) characteristics. This comparison is shown in Figure 9 where the residuary resistance coefficient is plotted as a function of speed. In describing the character of these curves, the first major peak in each curve is called the prismatic peak, so named because of its sensitivity to changes in the prismatic coefficient of the lower hull. The second major peak is the primary wavemaking drag peak which is present in all surface ships at about a Froude number of 0.5. In SWATH ships, this peak is

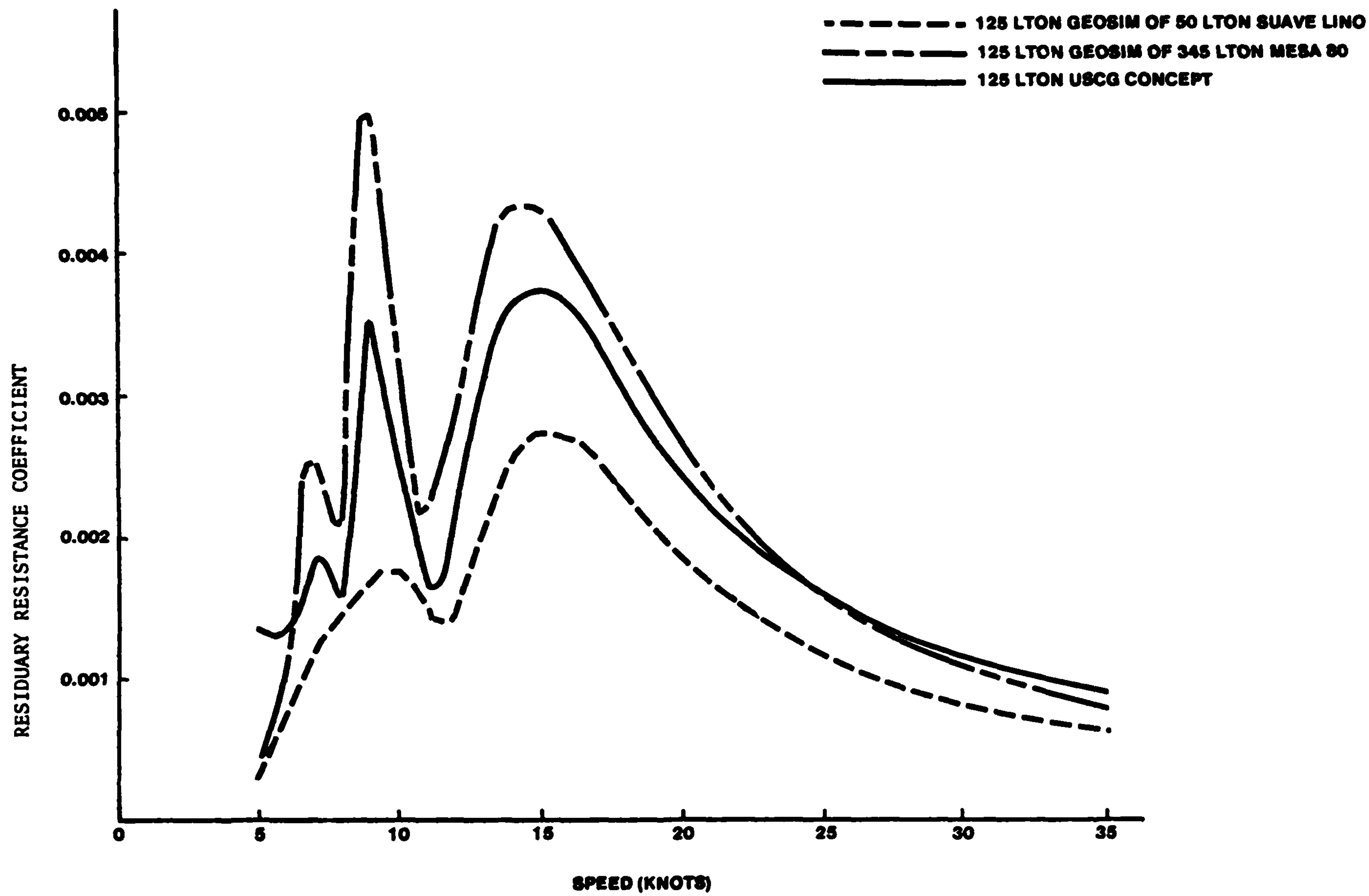


FIGURE 9 **COMPARISON OF RESIDUARY RESISTANCE CHARACTERISTICS FOR 125 LTON SWATH CONFIGURATIONS**

predominately governed by the cross-sectional area of the lower hulls and by the thickness of the struts. Also included in these curves are the wave-generating properties of the struts and a factor to account for the wave interference between the hulls and struts.

After the preliminary analysis, the baseline form for the 125-LTON concept was selected to be the geosim of the SUAVE LINO. Early in the geometry initialization phase, it was hoped that the concept could be helicopter capable and was lengthened accordingly. Later, in the process of achieving a balanced design, it was shown that the 125-LTON concept would not have the necessary carrying capacity to accommodate a helicopter and its required stores. As a result, in an effort to minimize structural weight and enclosed volume, the concept was shortened.

Upon examination of the resistance trends shown in Figure 9, it is not obvious, from a resistance viewpoint, why the particular configuration was chosen. As mentioned, for this case, it was discovered that sacrificing residuary resistance characteristics for reduced structural weight was a good compromise. Though the new configuration had greater residuary resistance, it did not result in a substantial reduction the structural weight fraction. These hull characteristics lead to a cruise speed of about 11 knots (selected because of the hollow in residuary resistance at that point) with a maximum speed dependent on the power installed. In the general case, reduced structural weight must be traded off against the increase in fuel required at the chosen cruise speed (note the significant difference in residuary resistance

in the 8-15 knot range) or the increase in cost of larger propulsion systems.

The hydrostatics of the resulting concept were then checked and adjusted as necessary. The beam of the 125-LTON concept was set somewhat high to provide the concept with high transverse stability to counteract the effects of the very narrow struts.

The 1250-LTON concept was configured using a similar process. The comparative residuary resistance curves for the 1250-LTON displacement are presented in Figure 10. Initially, for the 1250-LTON concept, the SUAVE LINO was used as the baseline. Again, because of helicopter landing and hangaring requirements, the ship was lengthened. The residuary resistance characteristics of the 1250-LTON concept appear much better than those of the 125-LTON concept, but it must be remembered that these were initialized around different mission requirements. The 1250-LTON concept was driven by the helicopter and hangar lengths, whereas the 125-LTON concept was more affected by the need to reduce structural weight and internal volume. The most economical cruise speed for the 1250-LTON concept would be in the 11-12 knot range with a second economic speed in the 15-16 knot range. The maximum speed is, again, dependent on the power installed.

This same exercise was performed, but in less detail for the 250- and 750-LTON concepts. Figure 11 presents the residuary resistance coefficient, as a function of speed, for all four concepts. Basically, the three larger sizes (250-, 750-, and 1250-LTON concepts) are geosims of one another, though this is not strictly the case. This explains

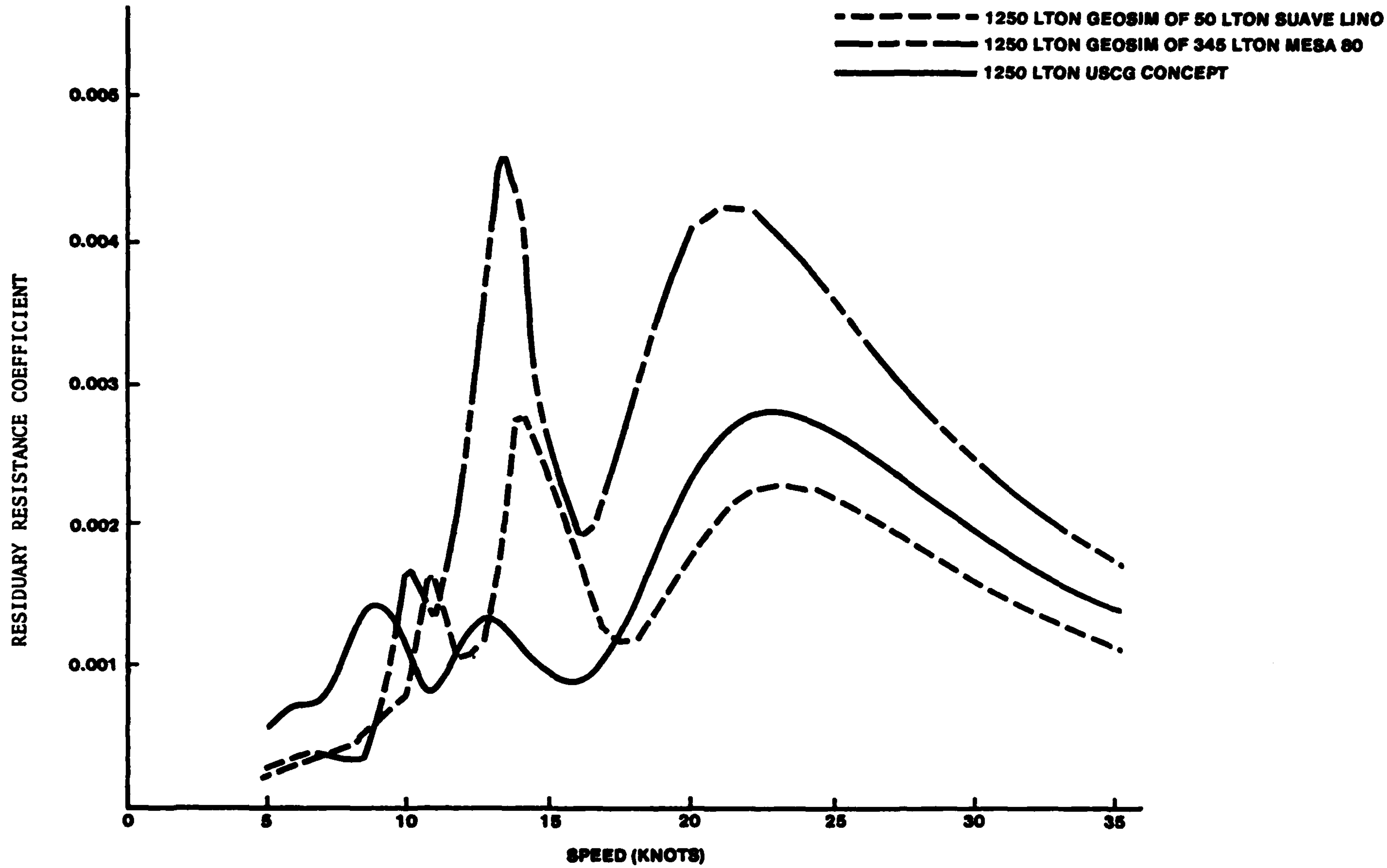


FIGURE 10 - **COMPARISON OF RESIDUARY RESISTANCE CHARACTERISTICS FOR 1250 LTON SWATH CONFIGURATIONS**

the similarities in their residuary resistance properties. It also demonstrates the effect of scaling on the location of the peaks and hollows in the residuary resistance curve, which occur at constant Froude numbers.

For this study, the key tools used in the geometry initialization process were three computer programs: one which predicts the resistance and powering characteristics of SWATH ships; one which predicts seakeeping behavior of SWATH ships; and the third provides estimates of structural weight.

The resistance and powering program, named "DRAG" was written by the late Dr. R. B. Chapman while he was employed at NOSC and is documented in the user's manual, [27]. The resistance calculation itself is based on classical thin ship theory as presented in Reference 28. The analytic predictions of this program have been compared against available model test data whenever possible, and against a limited amount of full-scale data. However, there is no model test data for the type of configurations proposed here. As a whole, the DRAG program provides predictions of resistance and powering characteristics of acceptable accuracy for this level of investigation.

The DRAG program calculates the frictional drag characteristics based on the ATTC friction curve with a model to full-scale correlation allowance of 0.0005 included. The bare hull drag characteristics and coefficients are calculated by summing the residuary resistance (with an empirical form factor of 0.0005 included) and the frictional drag. Bare hull EHP values are calculated based on the bare hull drag values.

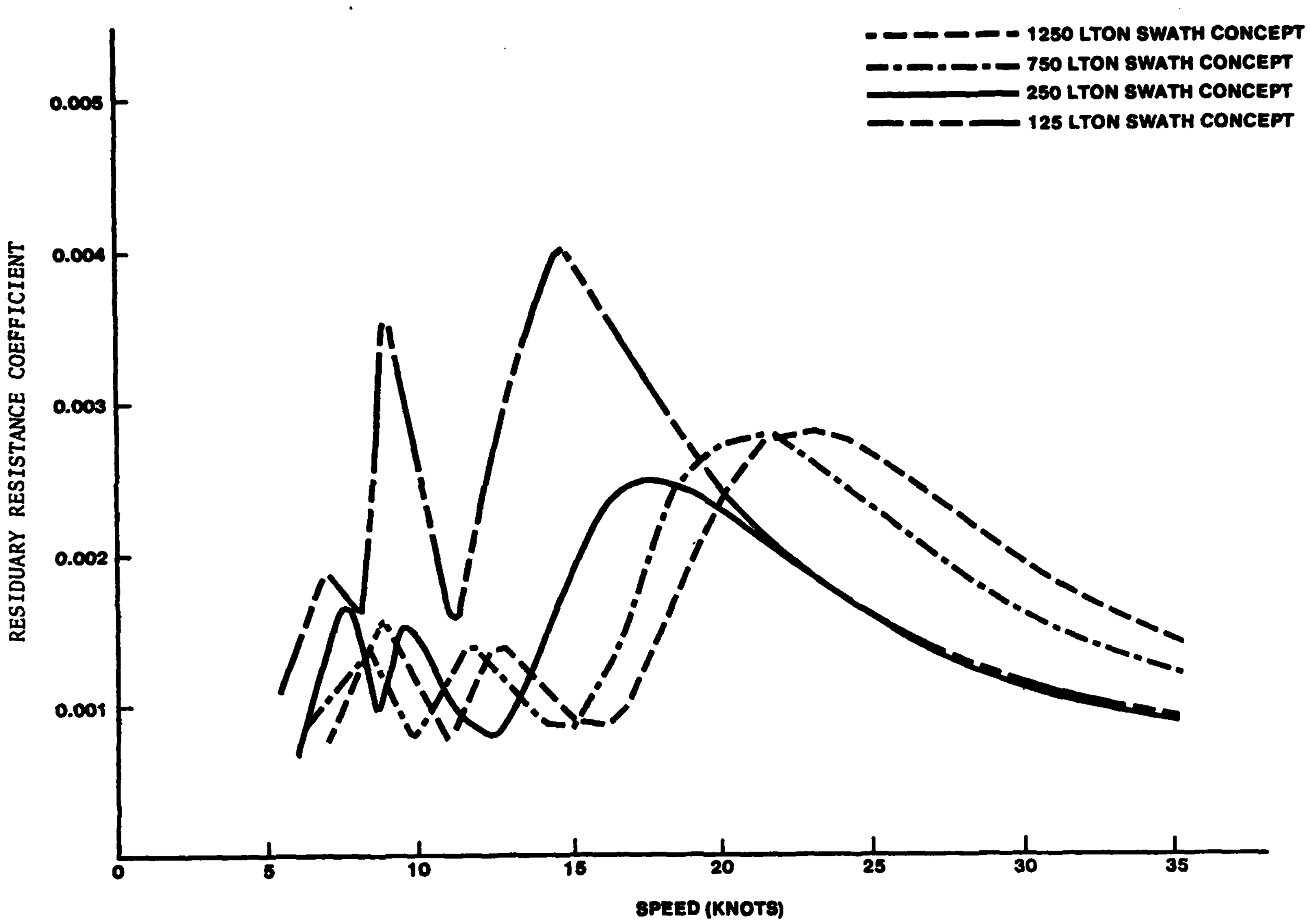


FIGURE 11 - **RESIDUARY RESISTANCE CHARACTERISTICS FOR 4 SMALL SWATH SHIP CONFIGURATIONS**

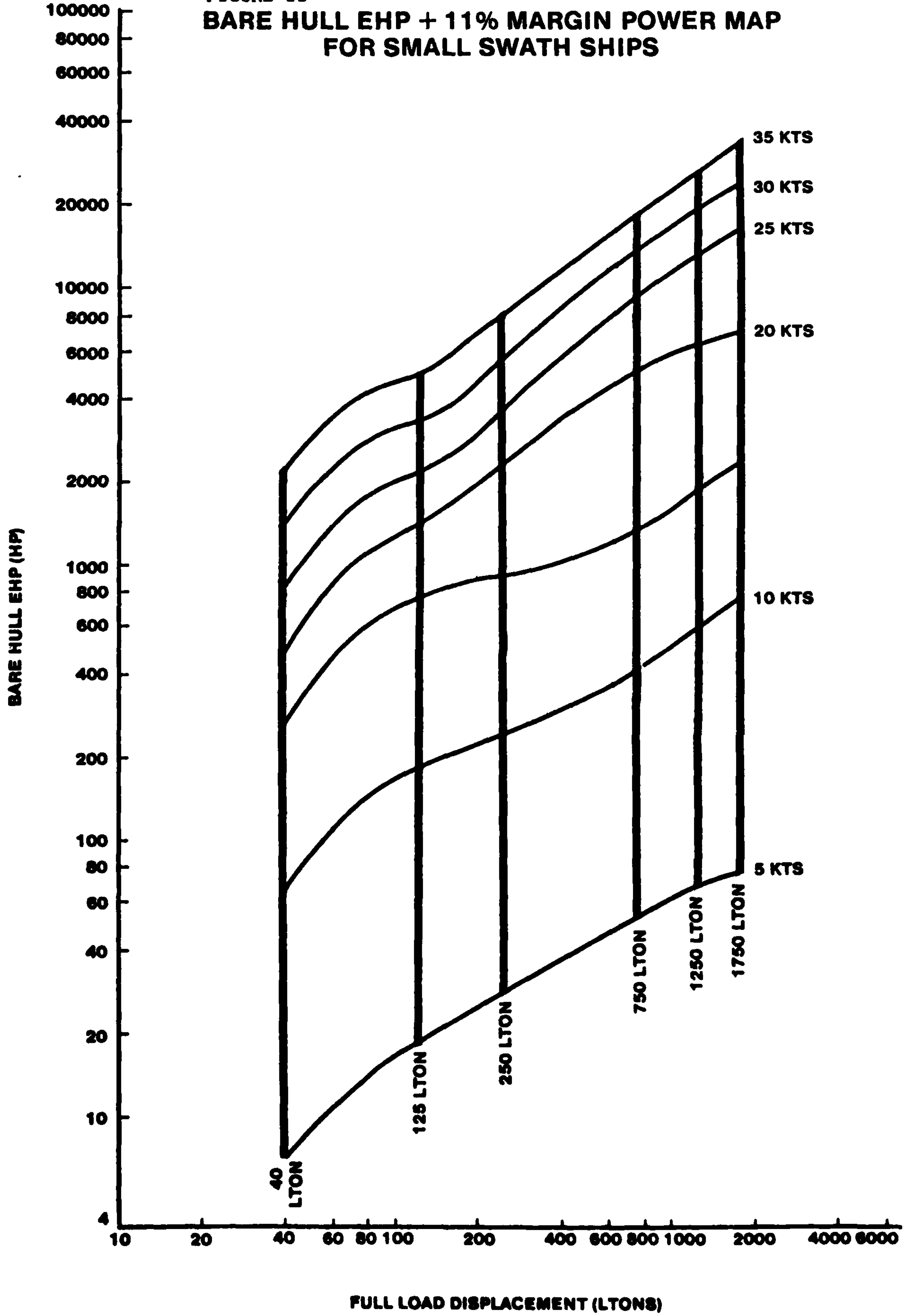
An 11% margin was then added to the predicted bare hull EHP, in accordance with Naval Sea Systems Command (NAVSEA) practice. The predicted bare hull EHP characteristics, as a function of full load displacement, based on the four concepts just described, are presented in Figure 12. It must be emphasized that Figure 12 is plotted on a log-log scale, and does not include appendage drag or still air drag. Appendage drag estimates were not included in this plot because the appendages (canards, stabilizers, and rudders) are not usually formally sized so early in the design process. The final resistance and propulsion data used for the concepts in this report did include appendage drag (approximately 3% of the total drag) but did not include still air drag.

The second key tool is one for predicting seakeeping behavior developed by Ms. Kathryn McCreight, of DTNSRDC. Her program is based on theory developed by Dr. Chung Lee, et al, [29], also of DTNSRDC. This program has not been as extensively validated, and does not include the significant effects of active control surfaces. However, it is a most useful and necessary tool, in that SWATH geometry initialization cannot be effectively accomplished without a close relationship being maintained between the resistance and seakeeping aspects of the concept.

The third tool provided estimates of the hull structural weight. This tool, though of less importance than the previous two, is critical to the geometry initialization process since structural weight normally accounts for some 40-50% of the ship's lightship displacement. The algorithm used was developed and programmed by the authors and is described in the structural weight section of this report. The parti-

FIGURE 12 -

BARE HULL EHP + 11% MARGIN POWER MAP FOR SMALL SWATH SHIPS



cular algorithm has not been validated for SWATH ships, but the method and much of the data incorporated within have been validated for planing craft, [30-32]. Further, checks against more detailed small SWATH ship designs have shown good agreement with the estimates made by the algorithm.

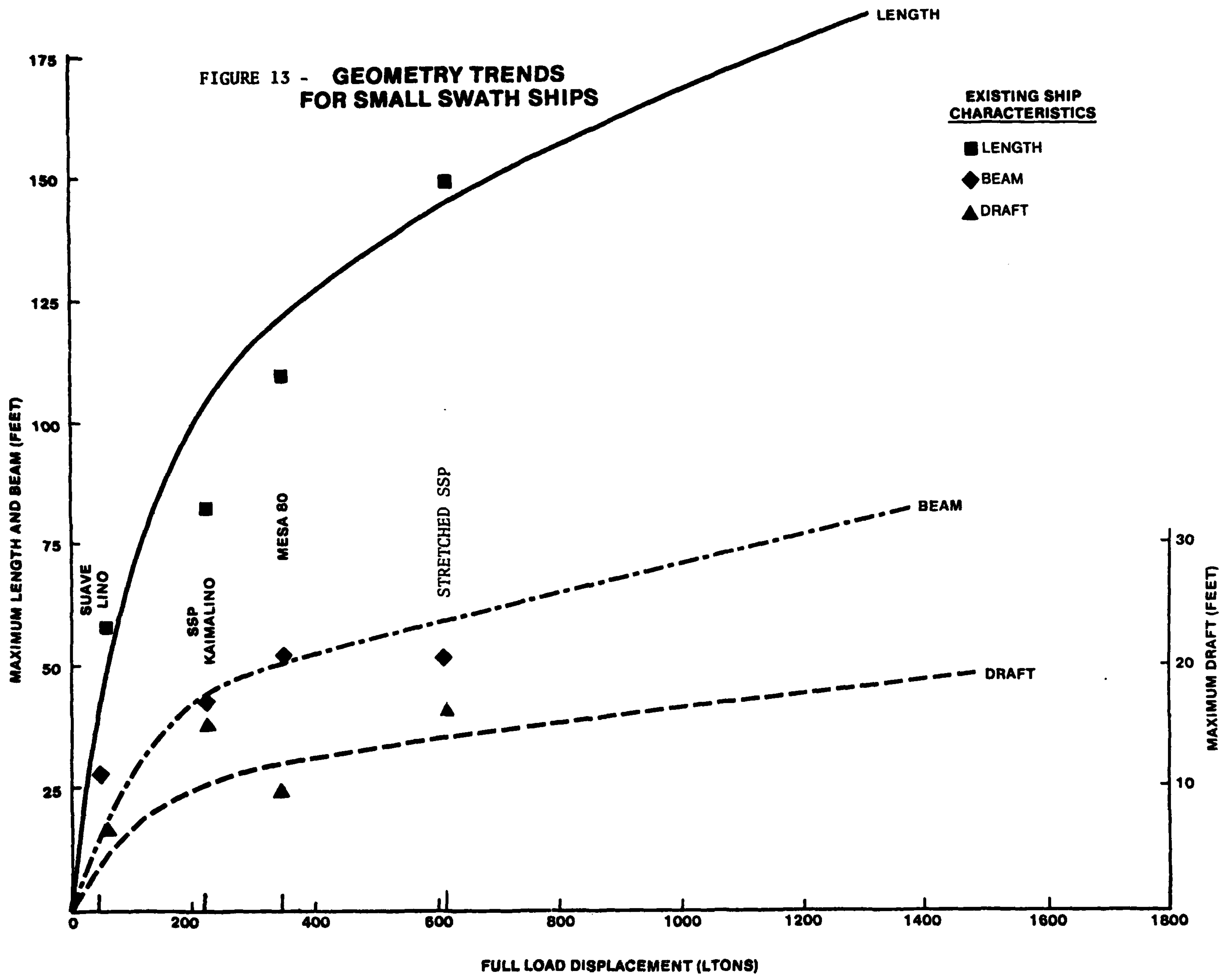
Geometric and hydrostatic properties of the four concepts are presented in Table 1. The gross geometry trends, as a function of full load displacement, are presented in Figure 13. The curves in this figure are based on the four concepts developed, and are shown with points representing existing SWATH ships and the proposed Stretched SSP overplotted. The curves presented are based on the assumption that concepts of less than 250 LTON will not have helicopter capability and concepts displacing 250 LTON or more will have helicopter capability. Note that there are two scales on the ordinate: one for draft and the other for length and beam. Another geometric characteristic, not presented in Table 1, but of use in the parametric study is the cross-structure clearance (the distance between the waterline and the bottom of the cross-structure). Figure 14 is a plot of the cross-structure clearance heights of the four concepts with actual data points over-plotted.

As mentioned previously, SWATH ships have low tons per inch immersion (TPI) characteristics. The values of TPI for these four concepts are presented in Figure 15, again, with actual data points overplotted. For the four SWATH concepts, the TPI values range from 0.55 tons/inch for the 125-LTON, to 2.45 tons/inch for the 1250-LTON and 3.04 tons/inch for a less developed 1750 LTON configuration. These

TABLE I CHARACTERISTICS FOR SMALL SWATH SHIP CONCEPTS

	125 LTON	250 LTON	750 LTON	1250LTON
LOA (ft)	85.6	117.1	165.0	193.6
BOA (ft)	40.3	53.5	68.2	80.6
DRAFTmax (ft)	8.6	11.6	16.5	19.4
Lstrut (ft)	78.4	111.5	157.7	186.4
t strut (ft)	1.6	1.9	2.8	3.3
Waterplane Area (ft2)	241.1	344.2	730.4	1020.8
Cwp	0.97	0.81	0.83	0.83
LCF (ft aft of hull nose)	40.9	48.4	70.5	83.3
L lower hull (ft)	77.6	103.0	145.7	172.1
DIAmax (ft)	6.2	7.8	11.1	13.1
Cp	0.80	0.78	0.78	0.78
LCB (ft aft of hull nose)	41.1	44.9	64.0	75.6
GML (ft)	19.2	18.2	28.8	34.0
GMT (ft)	11.6	12.5	8.1	9.5
TPI (LTON/in)	0.57	0.82	1.74	2.43
Manning	14	29	65	90

FIGURE 13 - GEOMETRY TRENDS FOR SMALL SWATH SHIPS



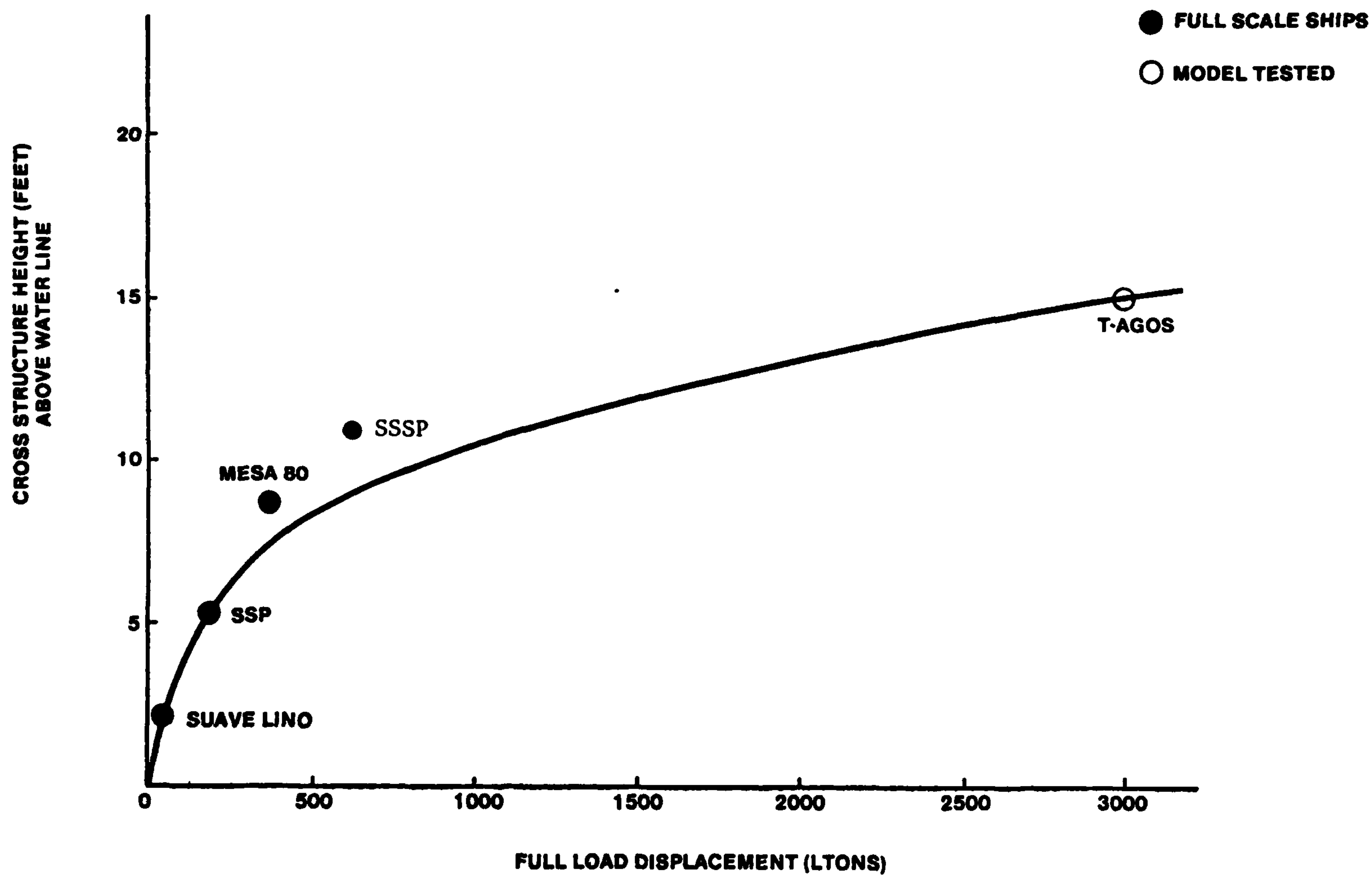


FIGURE 14 - **CROSS-STRUCTURE CLEARANCE VERSUS DISPLACEMENT FOR SMALL SWATH SHIPS**

are in contrast to the 3.05 tons/inch of the USCG 95 ft, 100 LTON WPB and 17.81 tons/inch for the 270 ft, 1750 LTON WMEC. The effect of the low TPI characteristics are discussed briefly in later sections of this report.

ARRANGEMENTS

The arrangement of SWATH ships tends to be straightforward. The majority of the volume of a SWATH ship (that contained in the cross-structure) is more easily arranged than the majority of monohull volumes simply because of shape, [33]. Whereas monohull spaces are frequently odd-shaped with different deck and overhead areas, particularly in the stern and bow regions, SWATH ship cross-structures are rectangular with the deck and overhead areas identical, throughout. The SWATH ship does have odd-shaped spaces in the sponsons, struts, and lower hulls, but these spaces are well used as fuel, liquid, and ballast spaces. In most cases, not all of the available volume in the lower hulls and struts can be used because of the limited carrying capacity of the SWATH concept, resulting from the low TPI properties, so some of these spaces must be designated voids. In SWATH ships larger than those considered in this report, the lower hulls could, perhaps, be used as auxiliary and propulsion system spaces.

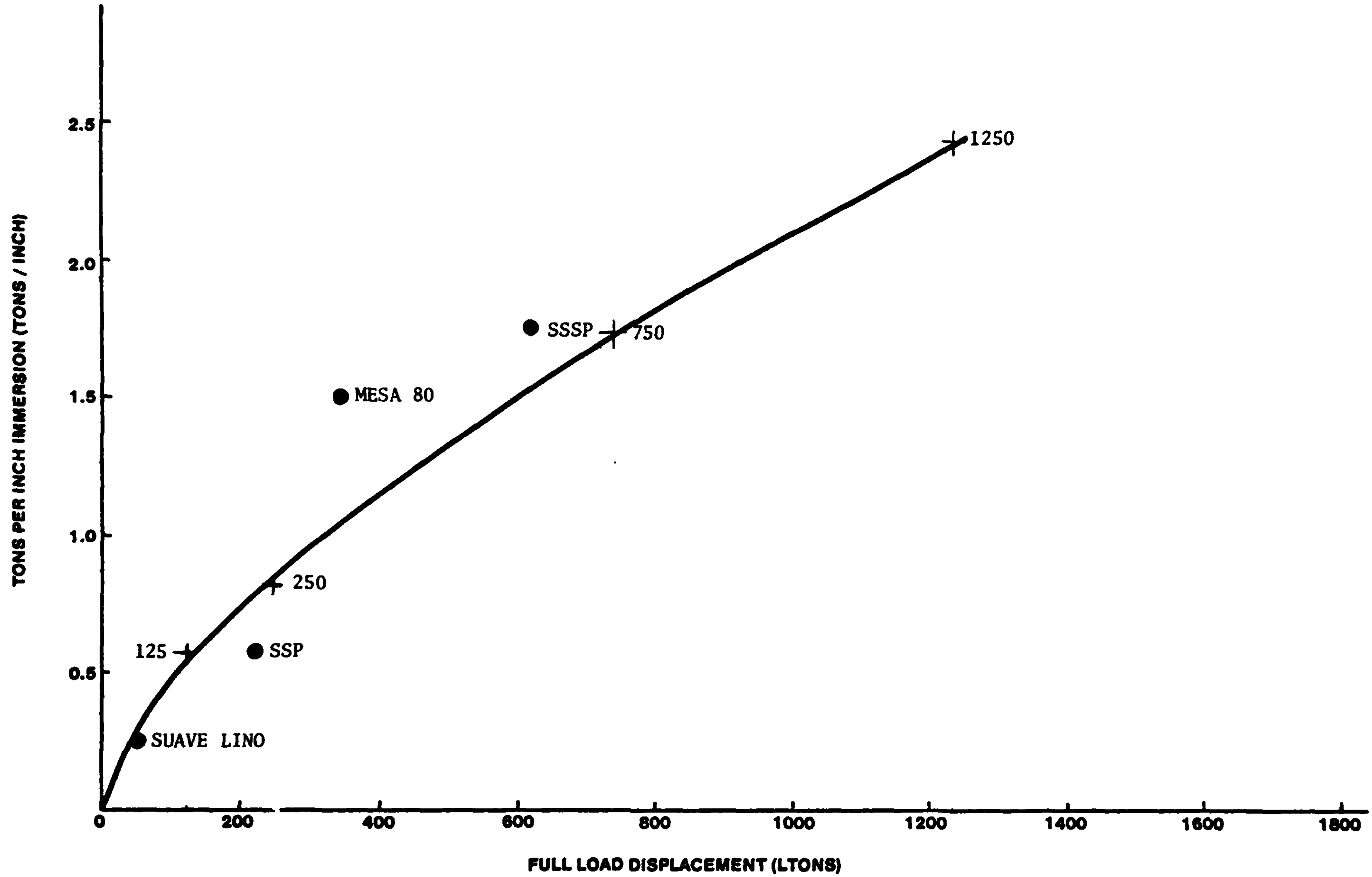


FIGURE 15 - **TONS PER INCH IMMERSION CHARACTERISTICS OF SMALL SWATH SHIPS**

Throughout the geometry initialization process, attempts were made to minimize the volume and associated structure inherent in these SWATH concepts. The key volume driver was total ship length, so length was kept at a minimum, but still consistent with helicopter landing requirements. Cross-structure depth was also minimized to limit volume. This resulted in generally unusable cross-structure decks (4 ft) in the smaller concepts. The 4 ft cross-structure decks are not entirely unusable: it is proposed to inset engine foundations on to the major beams in the cross-structure and allow them to stand above the main deck, then enclose the exterior portion of the engines in hard structure. It is also proposed to inset the deckhouse at the forward end of the ship. A "false floor" placed on the major beams in the cross-structure would serve as the deck for the deckhouse. Full sized decks (9 ft) become efficient in ships displacing approximately 300 LTON. In the two smaller SWATH ships examined here, the main deck is the damage control deck. As discussed in more detail in the "Damaged Stability" section of this report, the two smaller ships have been arranged to meet damaged stability criteria with close transverse watertight bulkhead spacing. Double bottoms were included in the 750- and 1250-LTON concepts, so the damage contr 1 deck is the top of the inner bottom.

A result of the emphasis on resistance and powering characteristics are the narrow struts proposed for the four concepts presented. On the 125- and 250-LTON concepts, the narrowness of the struts prohibit easy access to the lower hulls. As the small concepts have been postulated, the ship would require dry-docking or beaching for lower

hull access and maintenance. Strut thicknesses can be increased to allow for lower hull access, but only by impacting some other feature of the concept. For instance, keeping in mind the governing assumptions made earlier, increasing the strut thickness would allow the beam to be reduced, which may allow reductions in structural weight, but at a potential cost to both fuel economy and seakeeping quality. These concepts, as presented, are the authors' solution to a given problem and those used as the basis of the parametric studies performed herein, but are not, by any means, the only solutions to the given problem.

Detailed internal space allocation and arrangements are beyond the scope of this report. Rough checks were done to ensure that sufficient volume was available for various ship functions, such as living spaces, engine rooms, etc., in either the deckhouse or the cross-structure. The results were satisfactory and it is felt that there is sufficient internal volume in the deckhouse and cross-structure on all four concepts to accommodate the anticipated crews and missions.

The final configurations of the four SWATH concepts considered are presented in Figures 16 through 21. Figure 16 is the 125-LTON concept, Figures 17 and 18 represent the 250-LTON concept, with and without a helicopter, Figures 19 and 20 portray the 750-LTON concept configured for one helicopter and two helicopters, and Figure 21 shows the 1250-LTON configuration with one helicopter. Table 1 presents the general geometric and hydrostatic characteristics of the four concepts.

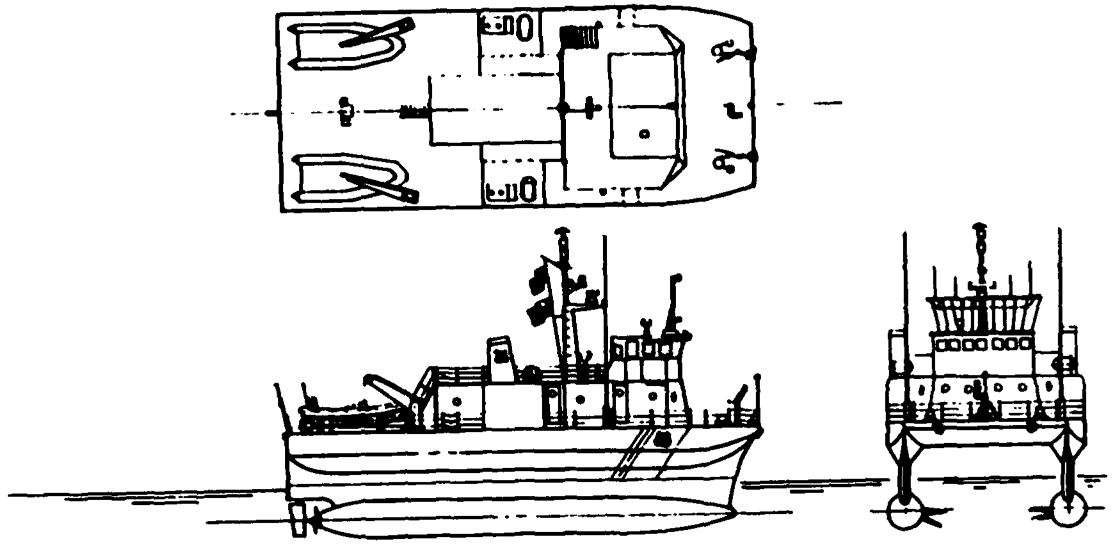


Figure 16 - 125-LTON WPB SWATH Concept

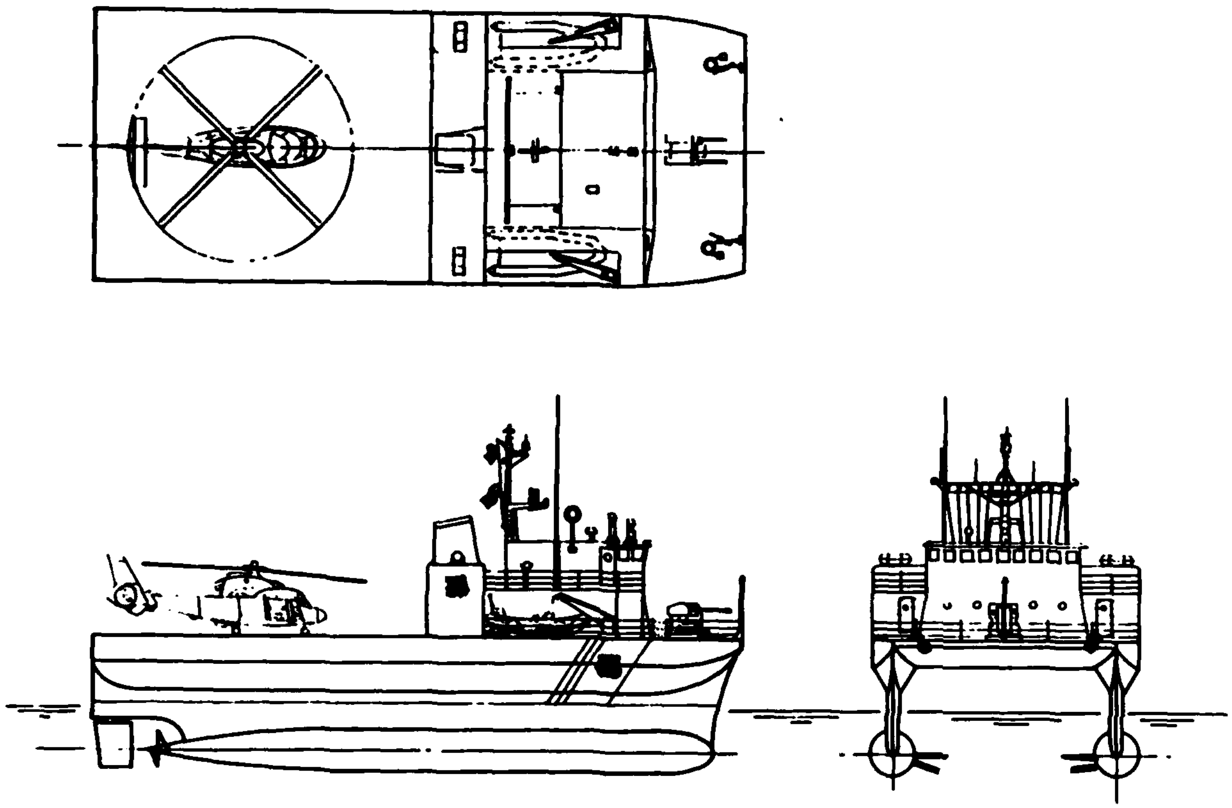


Figure 17 - 250-LTON WPC SWATH Concept

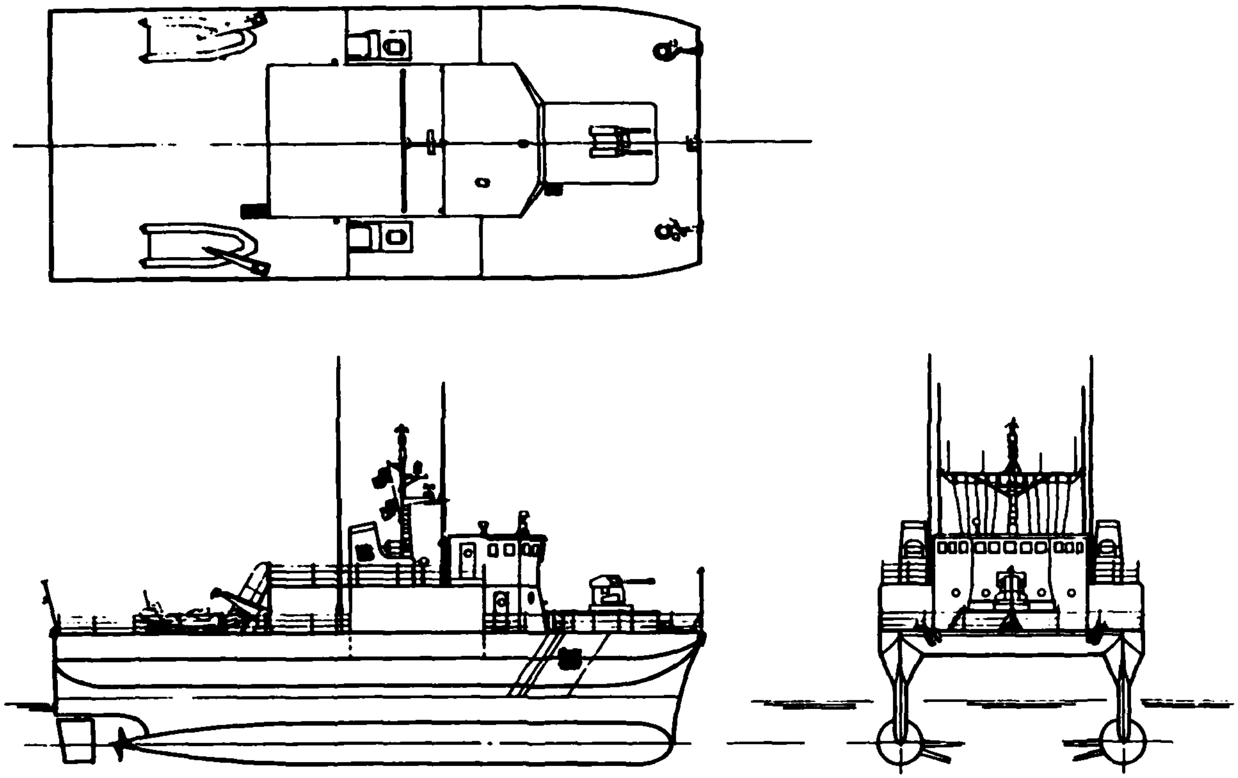


Figure 18 - 250-LTON WPC SWATH Concept with One Helicopter

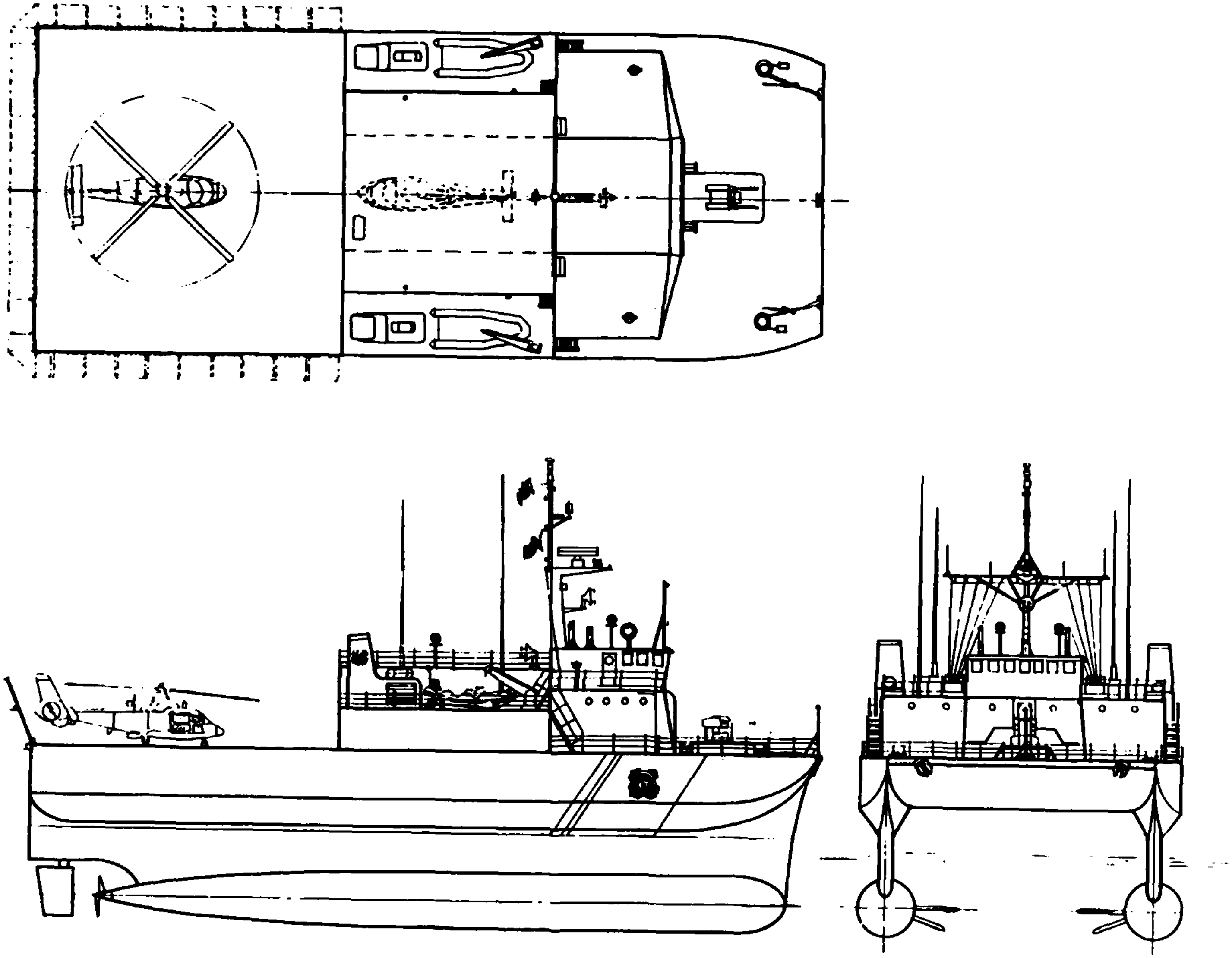


Figure 19 - 750-LTON WMEC SWATH Concept with One Helicopter

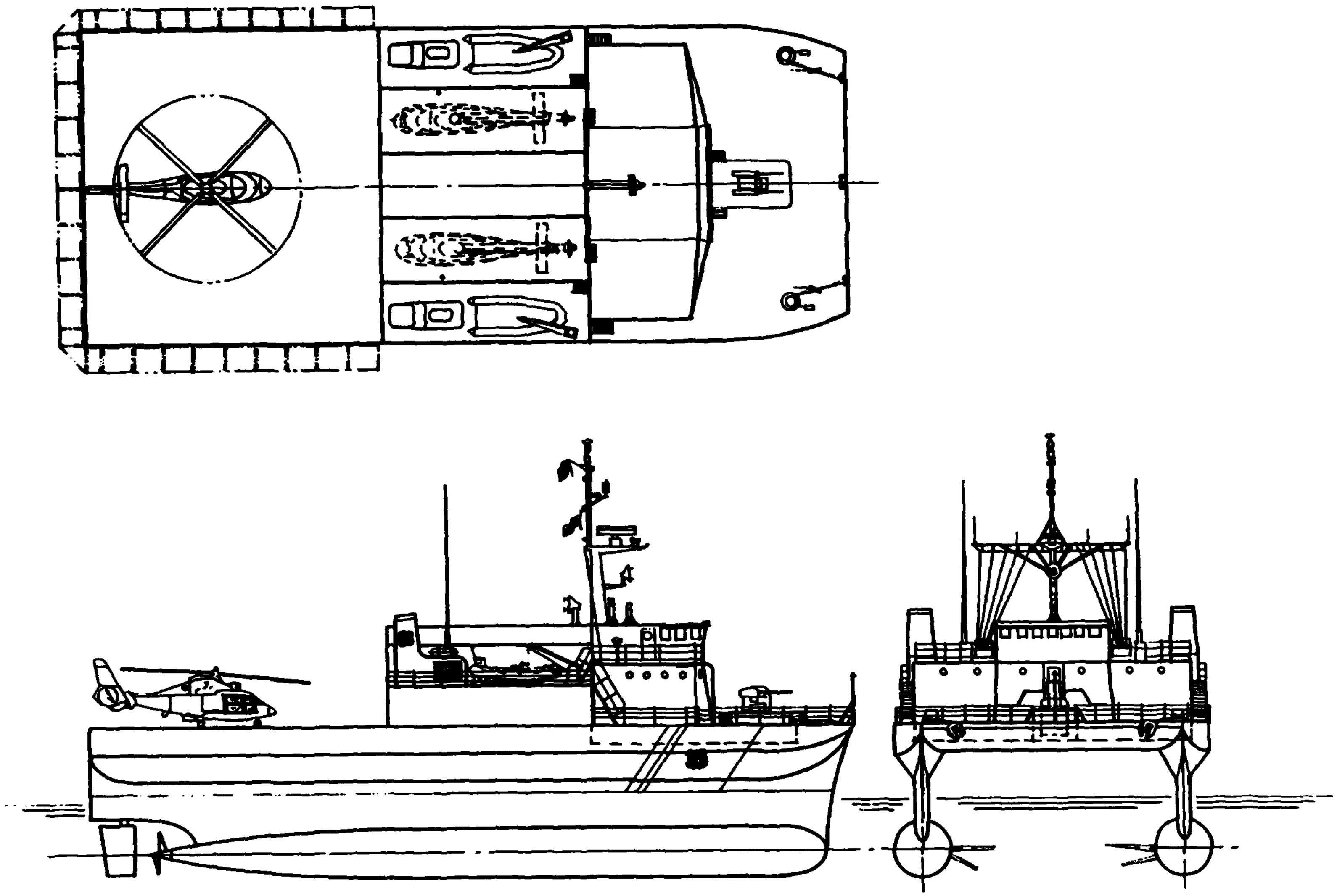


Figure 20 - 750-LTON WMEC SWATH Concept with Two Helicopters

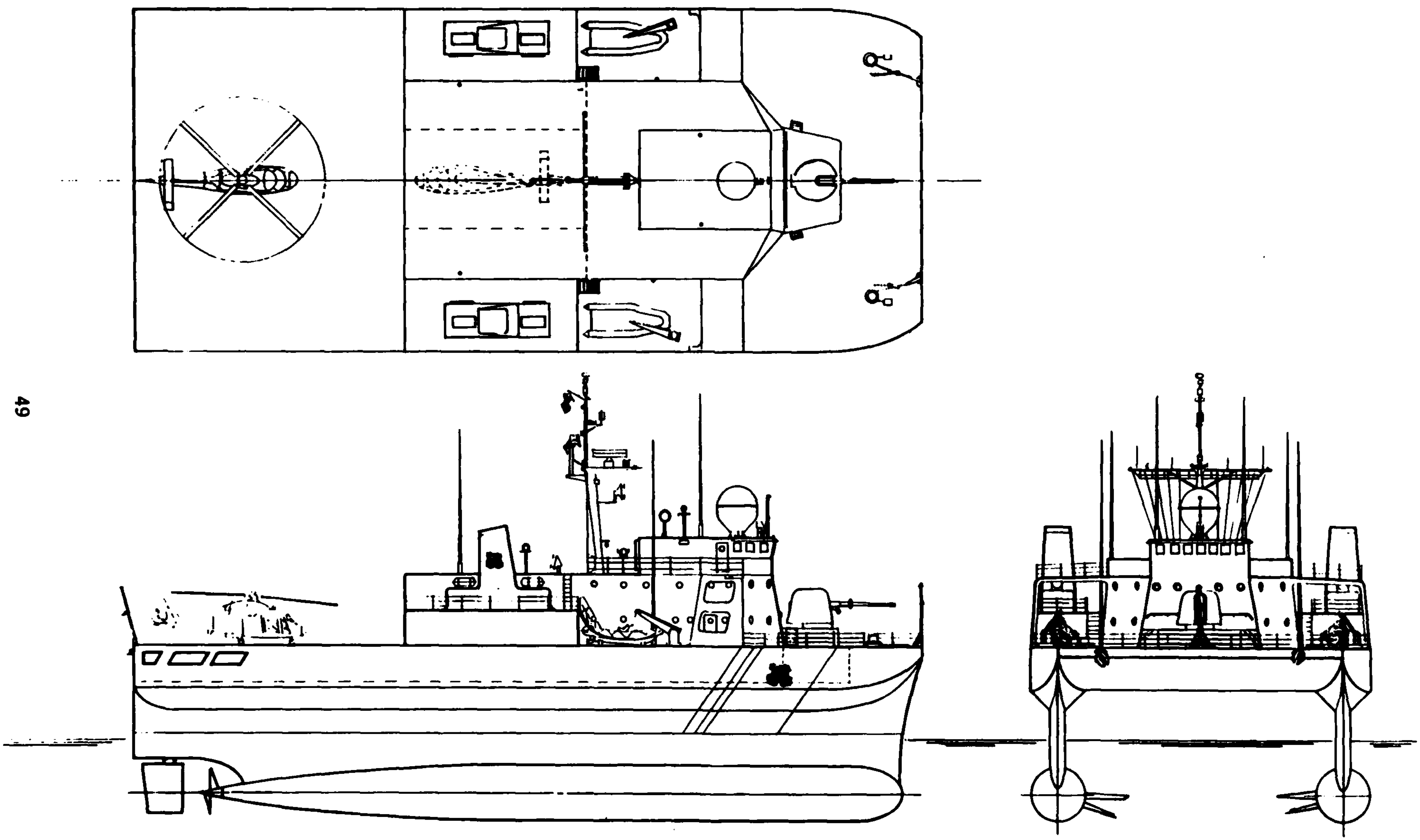


Figure 21 - 1250-LTON WHEC SWATH Concept with One Helicopter

STABILITY

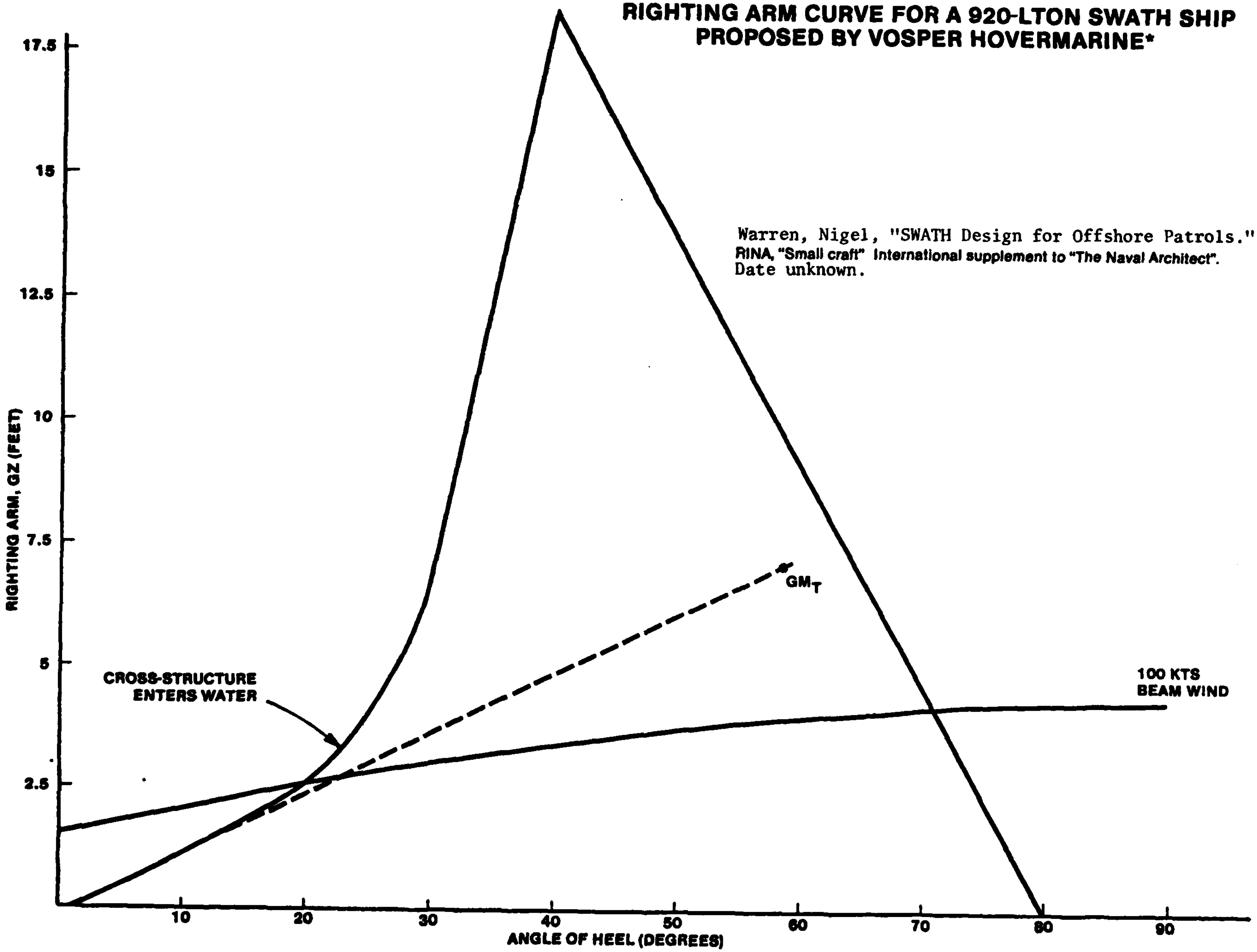
No intact stability calculations were made as these were beyond the scope of the task. Intact stability on the four concepts is not felt to be a problem. Figure 22, from Reference 33, shows the righting arm curve for a Vosper Hovermarine offshore patrol vessel. This figure is presented only as an example of a righting arm curve for a SWATH ship. Note the rapid increase in righting arm as the cross-structure begins to submerge. The intact stability characteristics of the concepts examined herein, though not the same, are not expected to be substantially different than those shown in this figure.

No damaged stability analyses were performed on any of the four concepts. It is felt, intuitively, that their damaged stability characteristics will be found to be satisfactory. If any of the four concepts is selected for further development though, it is highly recommended that a damaged stability analysis be performed on the concept. The intended structure (9 ft spacing of watertight transverse bulkheads in the lower hulls, struts and cross-structure, and a watertight longitudinal platform at the mid-height of each strut) should meet two compartment flooding criteria.

With the SWATH concept, the counter-flooding technique takes on new significance. If one strut or lower hull is damaged, the other strut or lower hull can be flooded to retain even trim and/or heel. The cross-structure provides a great amount of reserve buoyancy. It is proposed, for the smaller concepts, that the main deck be the damage

FIGURE 22 -
RIGHTING ARM CURVE FOR A 920-LTON SWATH SHIP PROPOSED BY VOSPER HOVERMARINE*

Warren, Nigel, "SWATH Design for Offshore Patrols." RINA, "Small craft" International supplement to "The Naval Architect". Date unknown.



control deck. The reserve buoyancy of the cross-structure is not lost if flooding can be contained by the transverse watertight bulkheads in the cross-structure. In the case of the larger concepts (750- and 1250-LTON), a watertight double bottom has been included, making the top of the double bottom the damage control deck.

INTERNAL VOLUME

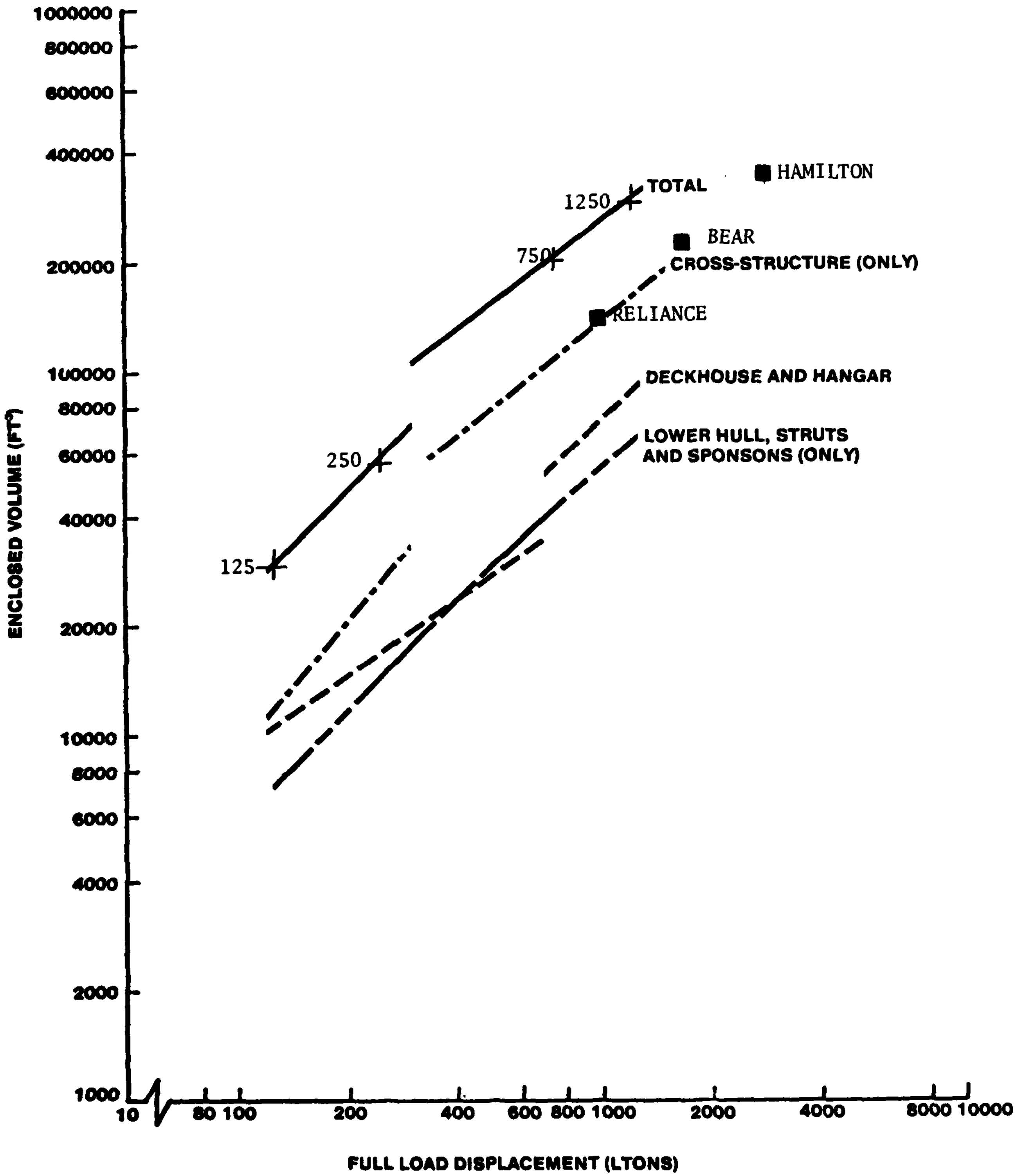
The twin hull aspect of the SWATH concept and the need to meet GMT requirements while maintaining a small waterplane area can result in a ship with an unusually large amount of enclosed volume and large deck area. This enclosed volume is not, in fact cannot be all usable volume. Table 2 is a presentation of the total enclosed volume of the four concepts developed here with an estimate of the enclosed volume of some of the existing USCG patrol craft. Upon examination of the table, the large volumes of the SWATH concepts in question become evident. The 750-LTON concept has slightly less enclosed volume than the volume of the 1750-LTON BEAR class and the 1250-LTON concept has slightly less enclosed volume than the 3000-LTON HAMILTON class. Enclosed volumes, as a function of full load displacement, for the various components of SWATH ships are plotted in Figure 23. The actual data points plotted are for total enclosed volume only. It should be noted that the plot is a log-log plot. The break in the "Deckhouse and Hangar" curve is a step function resulting from the incorporation of a helicopter hangar, which is thought to become a viable option at approxi-

TABLE II ESTIMATED ENCLOSED VOLUMES FOR THE SWATH CONCEPTS DEVELOPED

SWATH Concept:	125 LTON	250 LTON	750 LTON	1250 LTON
Lower Hull & Struts (ft3)	5000	10450	33530	50410
Cross-structure & Sponsons (ft3)	13810	31890	120410	176400
Deckhouse (ft3)	10640	17070	57640	90820
Total Enclosed Volume (ft3)	29450	59410	211580	317630

USCG Cutters:	210'	270'	378'
Hull (ft3)	129700	185200	253300
Deckhouse (ft3)	18000	55500	114500
Total Enclosed Volume (ft3)	147700	240700	367800

FIGURE 23 - **TOTAL ENCLOSED VOLUME CHARACTERISTICS FOR SMALL SWATH SHIPS**



mately 600 LTON. The break in the "Cross-Structure (Only)" curve represents a step function resulting from the inclusion of a full, usable deck in the cross-structure which becomes a practical option for these concepts at about 300 LTON. This is such a significant change in enclosed volume that it creates a similar step in the "Total" enclosed volume curve. The inclusion of a hangar does not seem to have as great an influence on the total enclosed volume characteristics.

In many instances, this large amount of volume (and, similarly deck area) is beneficial, but as implied earlier, it also has drawbacks. First, this larger volume must be enclosed by hull material, thereby increasing the structural weight fraction of the ship. Second, this volume, depending on the nature of the space, must be heated or cooled, insulated, painted and cleaned, thereby increasing the outfit and furnishing weight and consuming a portion of additional manpower. However, the larger amount of volume can, perhaps, be used to increase the quality of the living spaces, which would be beneficial from a crew morale viewpoint.

Deckhouses were sized for the specific area and volume needs of each concept. For the smaller concepts, the deckhouse is the center of all shipboard activity: ship control, berthing, living, workshops, etc. On the larger concepts with full depth cross-structure, these spaces could be much better dispersed and the deckhouses made smaller. Deckhouse volumes were checked by comparing the deckhouses selected against an algorithm from Reference 30. Volumes of all the deckhouses selected exceeded values predicted by the algorithm. Finally, the deck-

house volumes were checked against the deckhouse volumes of existing USCG cutters, with good agreement.

In general, SWATH ships differ from conventional monohulls with respect to carrying capacity and volume. In the past, monohulls were generally considered to be volume rather than weight limited. The case is the opposite for these SWATH concepts. As a result of the low TPI characteristics and the large volume of the concepts developed, these SWATH ships are weight constrained instead of volume constrained. Therefore, there is little weight carrying reserve in addition to that included in the initial design. Since these SWATH concepts have relatively high lightship/full load displacement ratios (averaging 70-80%), weight carrying reserve, in early stage design, is quite expensive in terms of displacement, i.e., one ton of reserve requires 3-4 additional tons of ship, if a thorough redesign of the ship is performed. However, in the early stage design, if more carrying capacity is desired, it can be obtained with less ship weight growth by only allowing certain weights and volumes of the ship to grow. The most efficient way of increasing the carrying capacity of a SWATH concept is to increase the strut thickness (hence WPA) and increase the lower hull diameter (hence the ship displacement). These increases have the effect of increasing ship displacement and carrying capacity at the cost of an increase in resistance characteristics and, perhaps, a small increase in ship motions, but with only minimal change in ship geometry, most importantly, internal volume. With minimal increases in internal volume, subsequent increases in ship subsystem weights (e.g., auxiliaries, electrical, outfit) are minimized. If this approach

(as opposed to a total redesign) is taken, one ton of additional weight carrying capacity can be attained at the cost of about 1-2 tons of additional ship. This points to the need for a strict weight control policy such as is adhered to in submarine construction.

SUBSYSTEM DEVELOPMENT AND WEIGHT ESTIMATION

Following the initial determination of the hydrodynamic, general arrangements, volume and area characteristics of the four concepts, the next step was to develop more detailed weight estimates for each of the major subsystems. Manning requirements were assumed to follow current USCG practice, with allowance for increased requirements for the more capable payloads. Crew sizes were selected, based on mission endurance and mission capabilities, in conjunction with USCG manning criteria. As a rule, it was assumed that a crew of 5-9, including an officer, could run the ship, depending on ship size, so the ship crew was estimated assuming three eight hour watches of 5-9 people. With the basic crew established, each concept was reexamined for features requiring greater manpower and the crew complement was adjusted accordingly. For example, for those concepts with helicopter capability, the crew complement had to be increased substantially. In adherence to current USCG helicopter operating practice, a deck crew of five, a boat crew of five and a fire crew of five were anticipated. In addition, for the helicopter capable ships, additional crew spaces were allocated to extra flight crew and maintenance personnel. When a con-

cept had a major payload item, such as a large gun, additional personnel were included for its operation. Also included in the crew estimates for each concept were boarding crew and prize crew requirements. There was little official guidance on crew complement from the USCG, so the numbers derived are subject to change, but probably will not substantially alter subsequent weight estimates. Figure 24 is a comparison of the nominal projected crew sizes for the SWATH concepts with the manning trend for existing USCG cutters. The somewhat larger crew sizes on the 750- and 1250-LTON concepts are a result of the number of personnel required for helicopter operations.

It should be noted that the USN Ship Work Breakdown Structure (SWBS) formed the organizational basis for the weight groups examined. There are, however, some deviations from the standard SWBS system. For example, machinery foundation weights have been included in Group 2 (Propusion System) weights instead of Group 1 (Structure) weights. In most instances, deviations from the standard SWBS will be noted.

PAYLOAD

Since no specific payloads were provided by the USCG, one of the first steps in the parametric study was to develop suitable payloads for each displacement concept. Lists of the final payloads used for each concept are included in Appendix A.

It was originally hoped that each concept would include a degree of helicopter capability. This analysis is based on the requirements

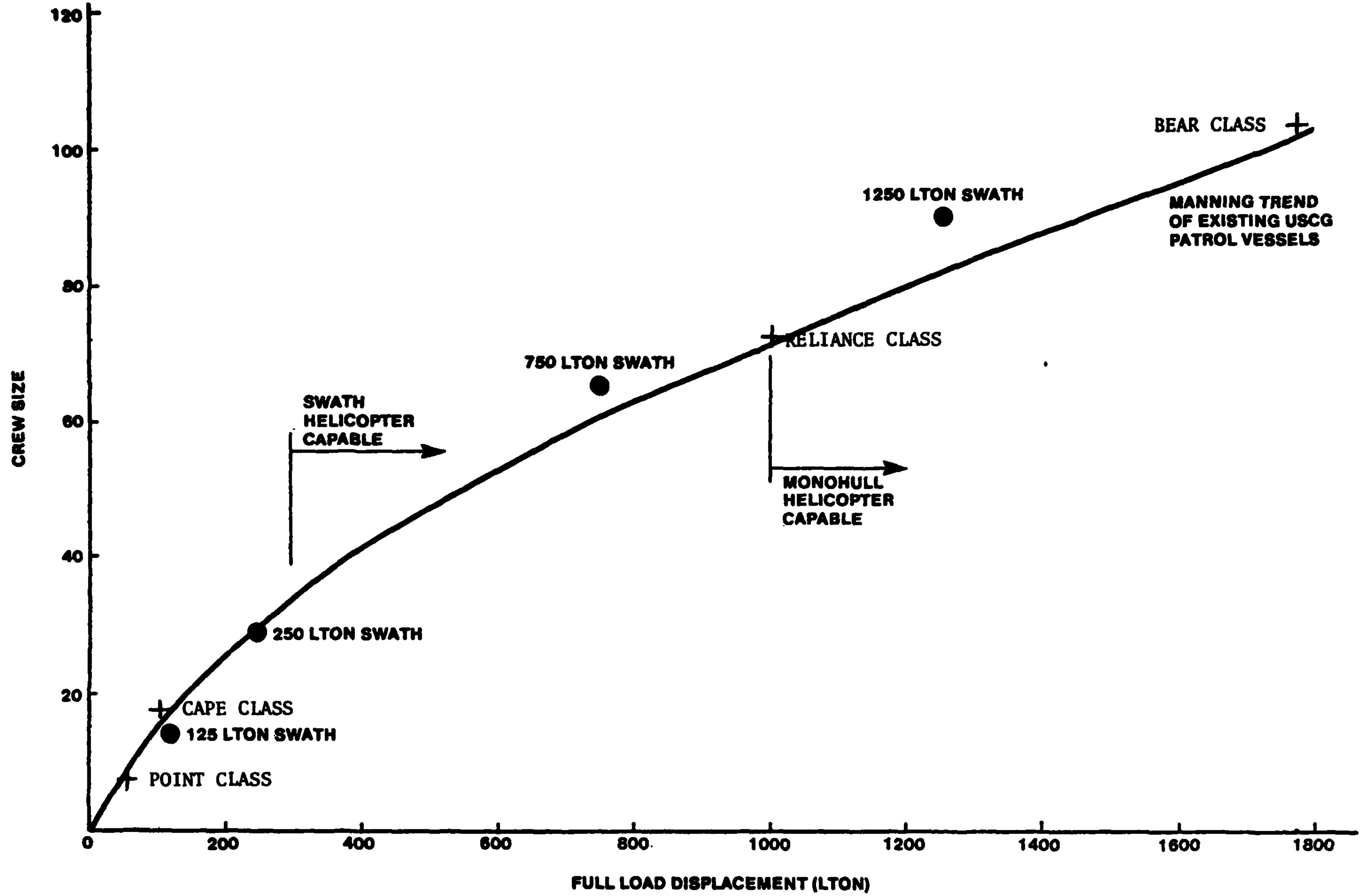


FIGURE 24 - **CREW SIZE TRENDS FOR EXISTING USCG PATROL SHIPS AND ESTIMATED MANNING REQUIREMENTS FOR SWATH CONCEPTS**

for the newest USCG helicopter, the HH-65A, DOLPHIN, [34]. After completion of the geometry initialization phase, it was apparent that the 125-LTON concept was too small for standard helicopter operations. The 125-LTON concept almost provides sufficient deck space, but does not have sufficient carrying capacity for a helicopter. The 250-LTON concept provides deck area for helicopter operations but very marginal carrying capacity. When aviation stores and fuel, extra crew requirements, and helicopter operation and maintenance equipment are factored in, it is not clear that the 250 LTON concept has enough payload capacity. At 750 LTON in displacement, the SWATH ship becomes large enough to not only handle the HH-65A, but also hangar it. There is sufficient deck area to hangar two helicopters, but there may not be sufficient carrying capacity for two helicopters and the accompanying crew, stores, fuel, parts and additional hangar structure. The 750 LTON may be made fully LAMPS III capable, but it is not clear that there is sufficient carrying capacity for all the LAMPS mission equipment and crew. The 1250-LTON concept can carry and hangar two helicopters and necessary supporting equipment and crew. Instead of carrying two helicopters the 1250-LTON concept could be made multi-mission capable or have longer range capability. If a smaller helicopter, such as the Hughes 500, were in USCG inventory the 125- or 250-LTON concepts could potentially be helicopter-carrying ships.

All four concepts meet the volume and weight requirements for operating, maintaining and housing remotely piloted vehicles operated either in the sea or in the air. The remaining portion of the payload for each

concept is comprised of armament, boats, crew and effects (including personal effects, food stores, and water).

A different armament suite is proposed for each concept. Small, removable guns are proposed for the 125-LTON concept whose mission is anticipated to be primarily SAR. Larger, fixed guns are proposed for the 250- and 750-LTON concepts because their missions will probably include ELT-mission work as well as some SAR. A large, very capable gun is proposed for the 1250-LTON concept whose mission will probably be primarily ELT.

The boats included in the payload weight estimates are 21 ft rigid hull inflatables. These inflatables are capable of making 30 knots and also may carry a 50 caliber machine gun, [35]. Included in the payload weight for each boat is a telescoping crane for launch and recovery of the boat.

The amount of crew effects included vary by concept, dependent on the anticipated mission length: 7 days for the 125-LTON concept; 14 days for the 250-LTON concept; and 30 days for the 750- and 1250-LTON concepts. The weight of personal effects was determined by assuming 0.22 LTON/man. Food stores were computed assuming 0.003 LTON/man/day and potable water weight was determined by assuming 0.15 LTON/man.

The cumulative payload weights for each concept are shown, as a function of full load displacement, in Figure 33. It must be noted that the payload weights plotted here include command, control, communication and navigation equipment, armament, helicopter and support

equipment, when applicable, and crew effects. It should be emphasized that the payloads listed in Appendix A are by no means fixed and are only those proposed by the authors in lieu of a specific USCG payload requirement.

HULL STRUCTURE

In general, hull structural weight estimates were made using a computer program which first estimates the hull structure based only on local loads, with uniformly distributed normal pressures. After initial scantling selection had been made by this process, the struts and hulls were checked for adequacy in resisting the transverse bending moment. If the bending stresses proved to be excessive, then material was added at the extremities of the sections in order to reduce the stresses to an allowable level. Since hulls of smaller vessels are predominantly governed by local loadings, this seemed to be the most efficient method to quickly converge on a reasonable structural weight estimate. This approach was utilized in the planing hull synthesis program, [30,31], which has been used in several small craft designs; some of which were eventually constructed. In these cases, the weights predicted were found to be in excellent agreement with those of the built craft.

The structural weight algorithm begins with a geometric description of the lower hulls and struts provided by the resistance program described previously. In estimating structural weight, a transverse

watertight bulkhead spacing of 9 ft and a transverse nontight bulkhead spacing of 3 ft was assumed for the lower hulls, struts and double bottom cross-structure. It was also assumed that there would be one horizontal watertight platform at the mid-height of each strut, and that the longitudinal nontight bulkheads in the cross-structure would have a spacing of 18 ft. The normal loadings assumed to act on the structure were based on standard practice, with hydrostatic loads, in a damaged condition, governing the majority of the structural loads. The hydrostatic design pressure was assumed to be equal to the pressure produced by the depth of water from the main deck to the location in question, with an additional 4 ft of water added. The exceptions to this were the helicopter deck and the underside of the cross-structure. The underside of the cross-structure, as well as the undersides of the sponsons were assumed to have equivalent static loadings of 60 psi resulting from wave impacts, based on the criteria and methods presented in Reference 32. Internal, nontight decks were selected on the basis of walking loads and set at 2 psi. Decks which would accommodate helicopters were assumed to have equivalent static loadings of 100 psi. Scantlings were then selected on the basis of the governing normal pressure loadings, either hydrostatic or impact, or due to helicopters, using algorithms presented in References 30 and 31 and plotted in Figure 25. In Figure 25, the curve labeled "Aluminum-Work Boat Construction" was used for the concepts with aluminum hulls and the "Steel-Modern Planing Ship" curve was used in the instances of steel hulls. Figure 25 was developed based on numerous design studies carried out in support of the

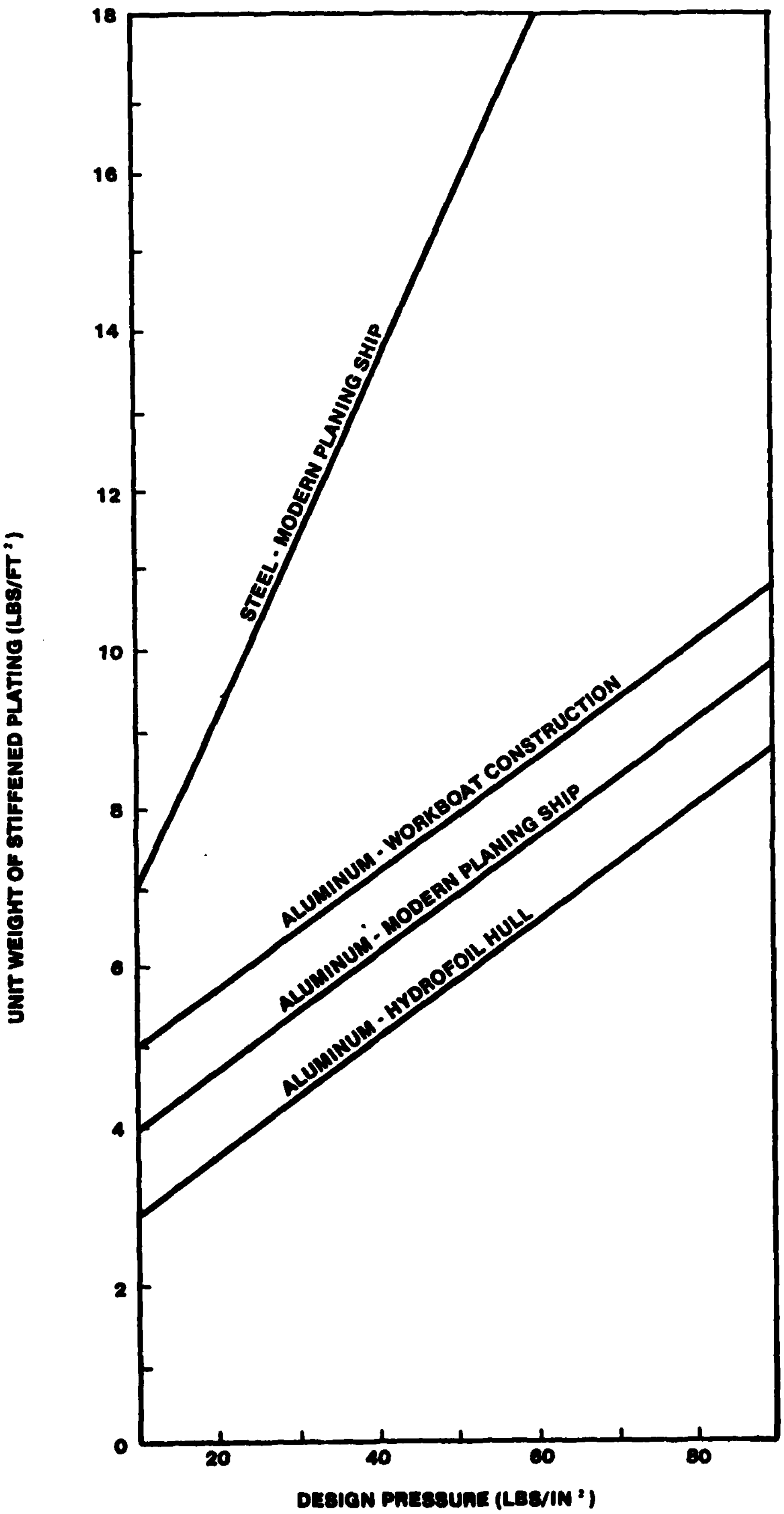


FIGURE 25 -
WEIGHT OF STIFFENED PLATING AS A FUNCTION OF DESIGN LOADS

development of the planing hull feasibility model, [30]. These and other data developed were then checked against existing planing hulls such as the CPIC-X and the PG-84. The planing hull structures module has since been used successfully to estimate the structural weight for new planing hull designs (SEA FOX) and has been utilized in the design phase of the USN's YP procurement.

With the initial scantling selection complete, a check of transverse bending moment was done. A simple beam theory calculation was performed with the applied moment calculated using an algorithm for side force estimation derived by Dinsenbacher and Sikora, [36]. The moment calculated is based upon a prediction of the maximum lifetime side force applied at mid-draft. According to Reference 36, this method has shown good correlation with the results of 13 SWATH models. However, none of the 13 models is representative of the configurations proposed herein. Trends of side force and moment as a function of ship displacement, for these configurations, using this algorithm, are shown in Figure 26. The stresses resulting from the transverse bending were then checked against allowable stresses (10,000 psi for aluminum and 18,000 psi for steel). If the initial stress was found to be greater than the allowable stress, the scantling sizes of the underside of the cross-structure and the upper 25% of the struts were increased accordingly.

Although a simple strength of materials (simple beam theory) approach is easy to accomplish, it has its limitations. In fact, a very recent study by Swanek and Sikora, [37], concluded that:

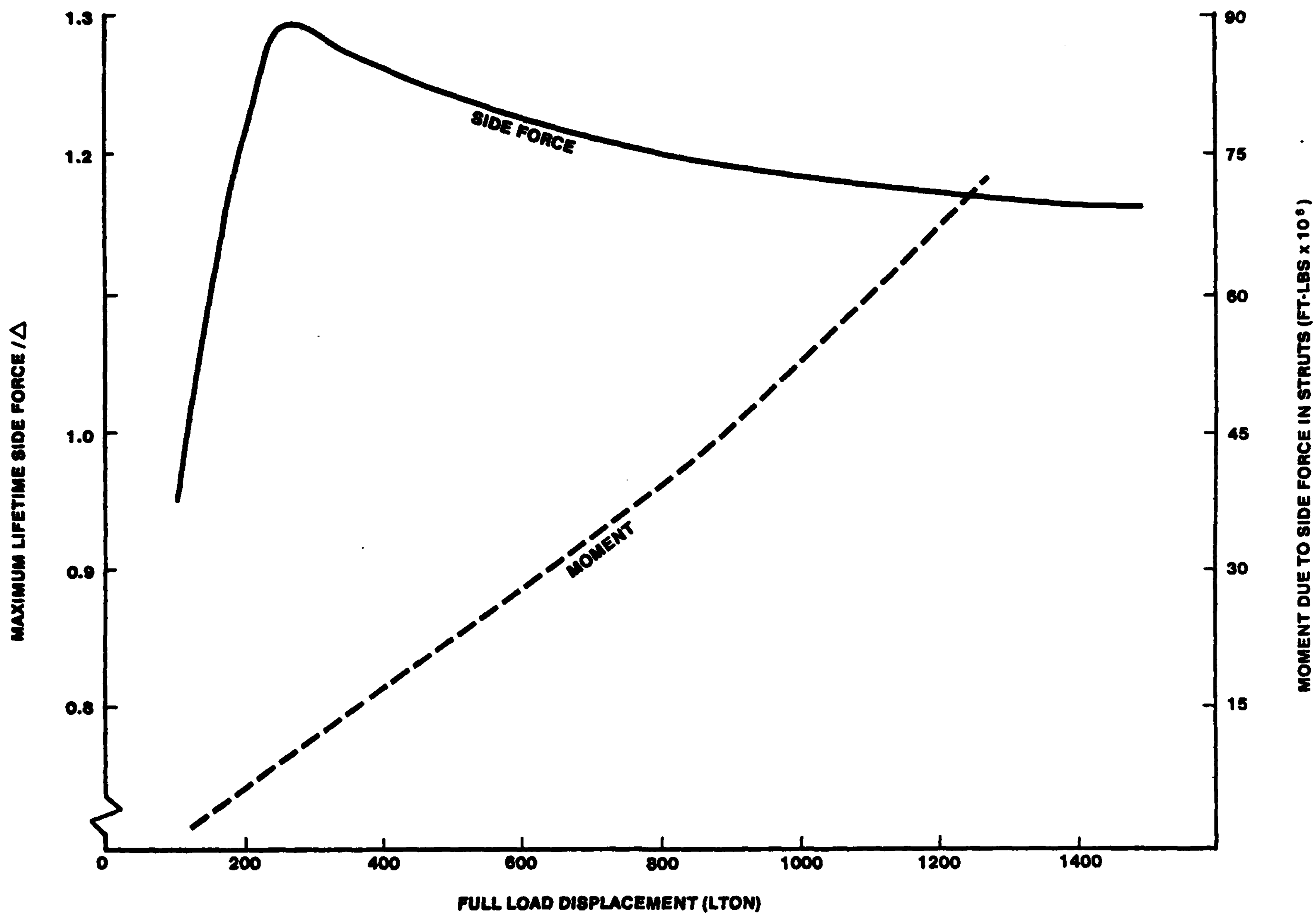


FIGURE 26 - **MAXIMUM LIFETIME SIDE FORCE & MOMENTS IN STRUTS FOR SMALL SWATH SHIPS**

"Simple strength of materials calculations are not adequate for predicting the magnitudes of the peak bending stresses produced with transverse loading."

This is because there are high stresses at the strut/cross-structure intersection, even when special attention is given to the design of this area. An illustration of this phenomena is shown in Figure 27, taken from Reference 37. This figure shows that even in a well designed haunch section (the one on the left), with comparatively generous radii, the actual stresses will be at least twice the stresses predicted by a simple beam theory approach. This means that under the lifetime maximum load conditions, the primary stress due to transverse bending moment alone, will approach the yield point of the material. This may be acceptable from a limit load viewpoint, but it raises questions as to the adequacy of the structure in fatigue.

For this reason, a brief fatigue analysis was conducted using data on aluminum from Reference 38 and data on steel from Reference 39. Reference 36 presents predicted fatigue spectra for a number of SWATH concepts in the form of side force/displacement as a function of the number of times a particular side load is equalled or exceeded in the lifetime of the ship. The data used in the fatigue analysis performed in this study was derived from Reference 36 and is similar to that shown in Figure 28. The stress levels at several levels of exceedance (10^6, 10^7 and 10^8 cycles) were derived, based on the design allowable stresses of 10,000 psi for aluminum and 18,000 psi for high tensile steel, and compared to the fatigue stress levels, [38, 39], at the above mentioned

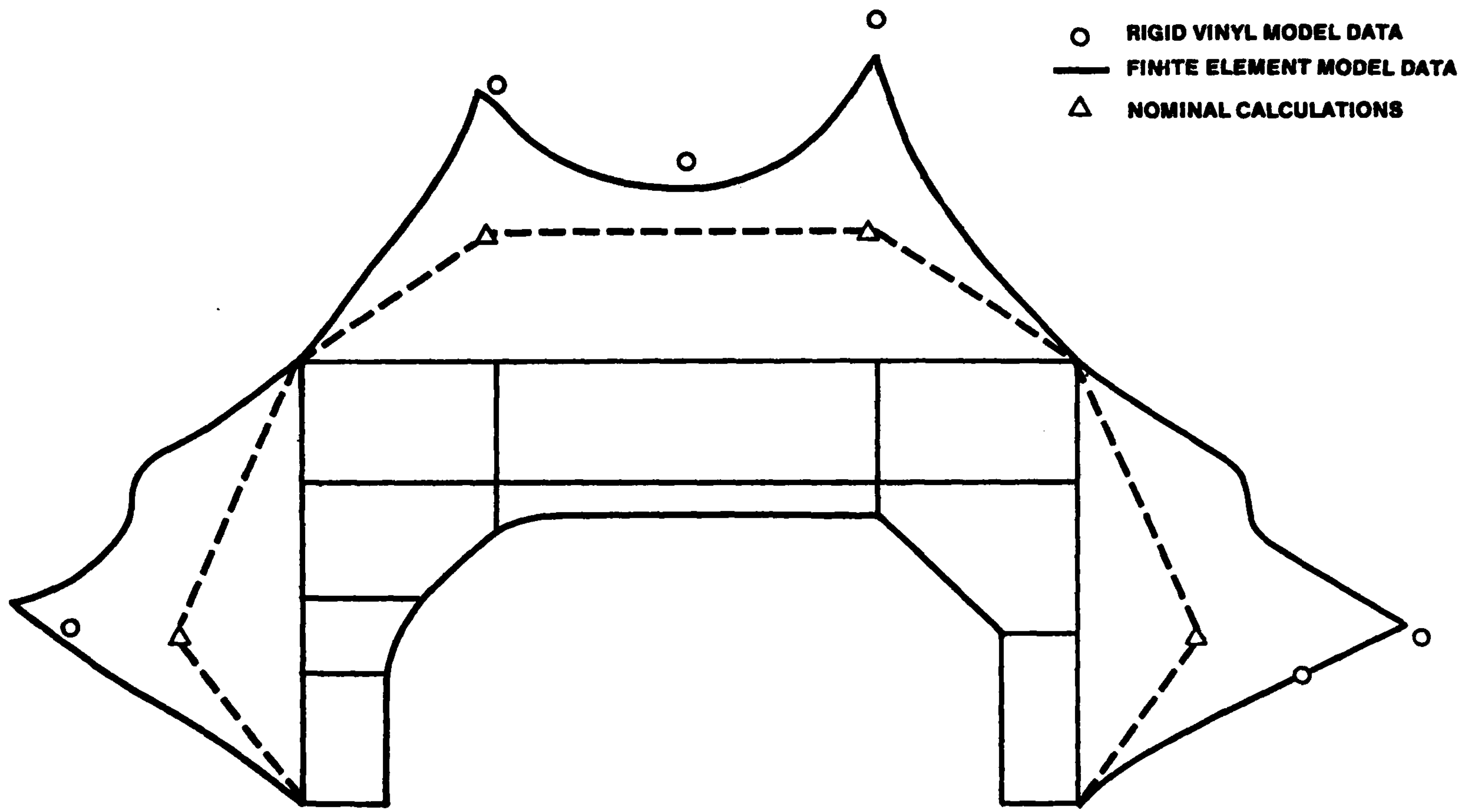


FIGURE 27 - **TRANSVERSE STRESS DISTRIBUTION OF OUTER SHELL PLATING AT TRANSVERSE BULKHEAD**

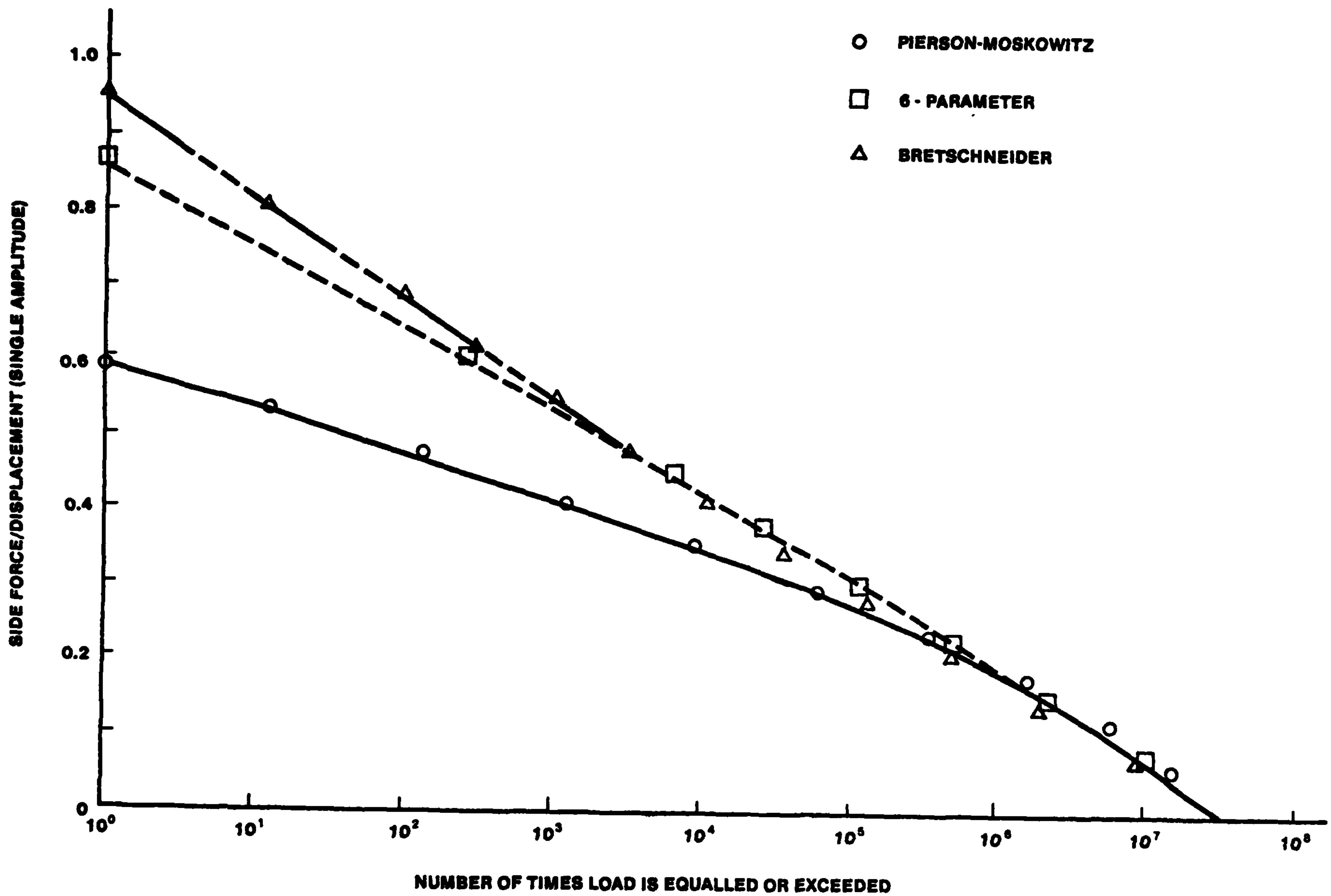


FIGURE 28 - **FATIGUE SPECTRA FOR A 3000 LTON, SHORT STRUT SWATH SHIP**

levels of exceedance. The stress levels averaged about 60% of the fatigue stress for aluminum and about 50% of the fatigue stress for the high tensile steel. This translates into a factor of safety on the fatigue stress level of 1.7 for aluminum and 2.0 for the steel. These levels were considered acceptable for the high tensile steel, but not for the aluminum. Because of the sensitivity of aluminum to fatigue and because of possible stress concentrations that could be generated during construction (aluminum is more sensitive to construction processes than is steel), it was decided that a safety factor of 4 on the fatigue stress should be the minimum acceptable in aluminum. The design allowable stress for aluminum, due to transverse bending, was accordingly reduced to 4000 psi. This resulted in stresses at the high levels of exceedance that averaged 22% of the endurance stress or a factor of safety of about 4.4, which, in turn, resulted in an increase in the structural weight of the larger ships.

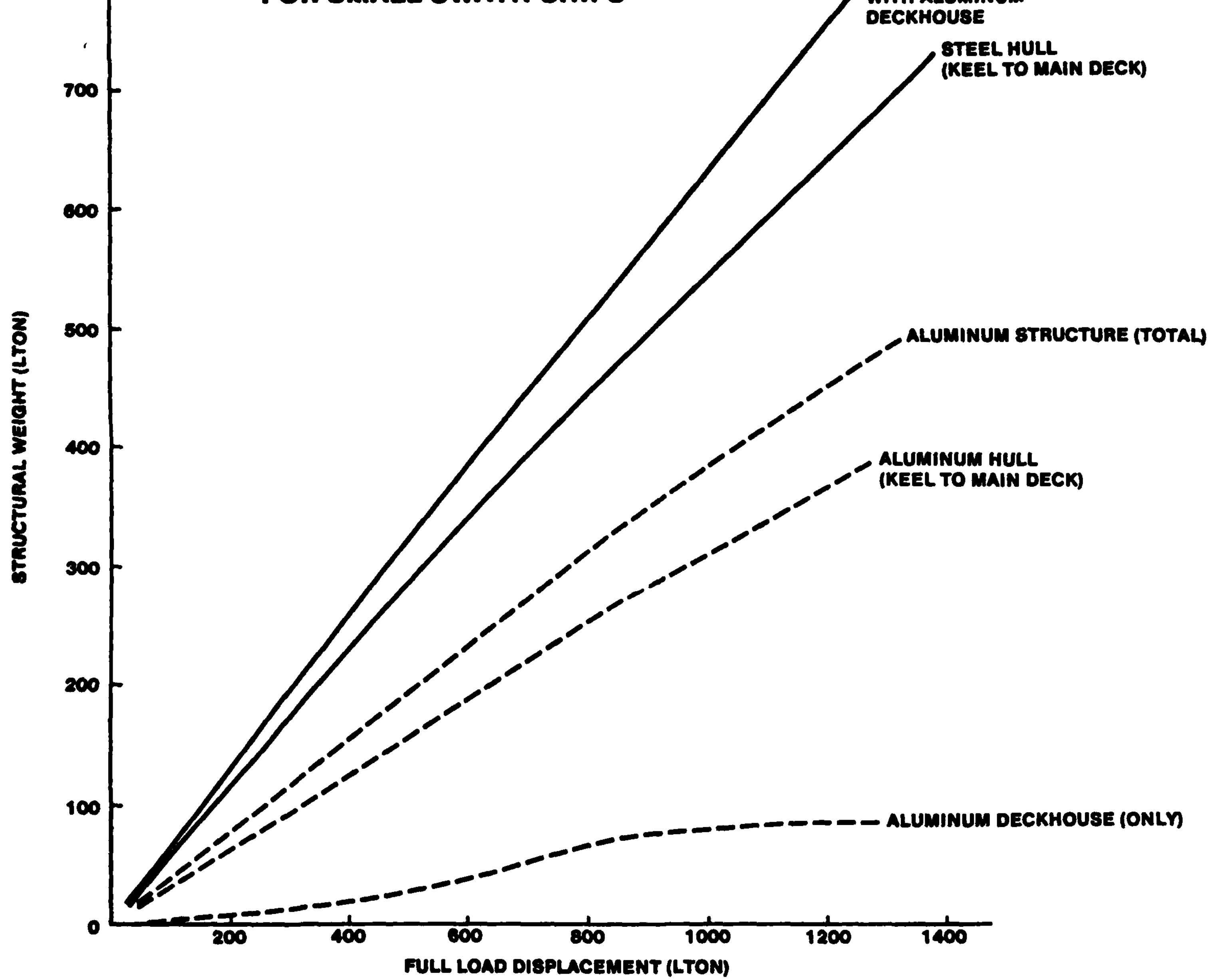
Structural weight proved to be less sensitive (than it was first assumed to be) to hull box depth. The shallower the box depth, the more overall bending loads governed the design, and subsequently, the additional structure necessary to overcome the increased bending requirement added back a portion of the weight reduction achieved by reducing cross-structure depth. As a result, full height decks (9 ft) were incorporated in the 750- and 1250-LTON concept cross-structures. Box depths of 4 ft were assumed for the 125- and 250-LTON concepts.

Deckhouse weights were obtained by determining the area of the various bulkheads and multiplying by a plate weight term obtained from the "Aluminum-Work Boat Construction" curve in Figure 25.

Structural weight estimates were made for both aluminum and steel structures for each of the four concepts. All structural weight estimates were increased by 5% to account for structural detailing. Finally, a 15% margin was added to account for uncertainty in the weight estimate The results are presented in Figure 29, plotted as a function of full load displacement. It should be noted that in all cases a nonprimary load-carrying, aluminum deckhouse was assumed. So, the "Steel Structure (Total)" curve represents a SWATH ship with steel lower hulls, struts, and cross-structure and an aluminum deckhouse.

As a result of the weight penalties of an all-steel ship, aluminum/steel composite cross-structures were examined. In the instance where the lower hulls and struts are steel and the cross-structure is a composite of aluminum and steel, and the aluminum is considered to be parasitic, i.e., considered to be noncontributing to the transverse strength, the structure will actually be heavier than an all steel cross-structure which contributes to the transverse strength. In the case of a composite cross-structure which contributes to the overall transverse strength of the ship, the weight is somewhat reduced from the all-steel alternative. However, the reduction is minor, and it is questionable whether the potential weight saving is worth the increased risk, cost, and complexity of a composite structure.

FIGURE 29 - STRUCTURAL WEIGHT TRENDS FOR SMALL SWATH SHIPS



POWERING AND PROPULSION SYSTEM

The propulsion system selected for these SWATH concepts is second in importance, from a weight standpoint, only to the structure, and in fact, may be the primary cost driver of the designs. The objectives of this study included an examination of range as a function of maximum speed, and the impact of the propulsion system weight on these and other parameters of a SWATH ship, including the ship's weight and volume.

In order to perform this parametric study and trade off factors such as range, speed, and propulsion system weight, a data base of existing engines and their performance was needed. Therefore, the first step in evaluating and selecting propulsion systems was to gather data for existing and planned engines - diesels and gas turbines, of both US and European manufacture. The main parameters of interest were physical dimensions, weight, brake horsepower (BHP), speed (RPM), and specific fuel consumption (sfc).

The first step in selecting suitable propulsion systems was to determine the location of the engines, thereby determining the type of drive system required. This was accomplished by comparing the piston or cylinder liner removal height requirement of each engine, plus foundation height with the lower hull diameter of the concept. The results of this analysis indicated that to attain top speeds of 20 knots or greater, neither US nor European manufactured diesels could be easily placed within the lower hull. Most of the gas turbine systems could be placed in the lower hulls and still provide maximum speeds of over

20 knots; but, in general, the thinness of the struts would prohibit easy access to engine rooms in the lower hull and make gas turbine removal difficult. Furthermore, it would be difficult to provide adequate intake and exhaust trunk volumes within the struts. Therefore it was decided that for all propulsion systems, the prime movers would be located on the lowest deck in the cross-structure possible and be connected to the propeller by a mechanical Z-drive transmission system. The Z-drive transmission system selected, as shown in Figure 30, has twin vertical drop shafts between the horizontal shafts located at engine and propeller levels and two sets of double bevel gears. The USN has had experience with this type of drive system in the hydrofoil AGEH-1, the USS PLAINVIEW, [40]. None of the components of the drive trains (bevel gears, shafting, bearings, etc.) proposed need be of a more advanced technology than that used in the AGEH-1. This type of drive system has been applied to the SWATH concept in Mitsui's MESA 80, [19-20]. Mitsui spent considerable time and effort developing and trialing their twin shaft Z-drive, and, to the best knowledge of the authors, have had no problems with the system. The transmission system of the SUAVE LINO is also a Z-drive, but incorporating only one vertical drop shaft, and also has proven to be quite successful.

Assumptions concerning the propeller configuration were necessary to estimate SHP and other propulsion system parameters. Propeller selections were made utilizing the resistance data generated in the initial hull sizing process and data from model scale powering tests, [41, 42]. A propeller was selected for each maximum speed, and for each dis-

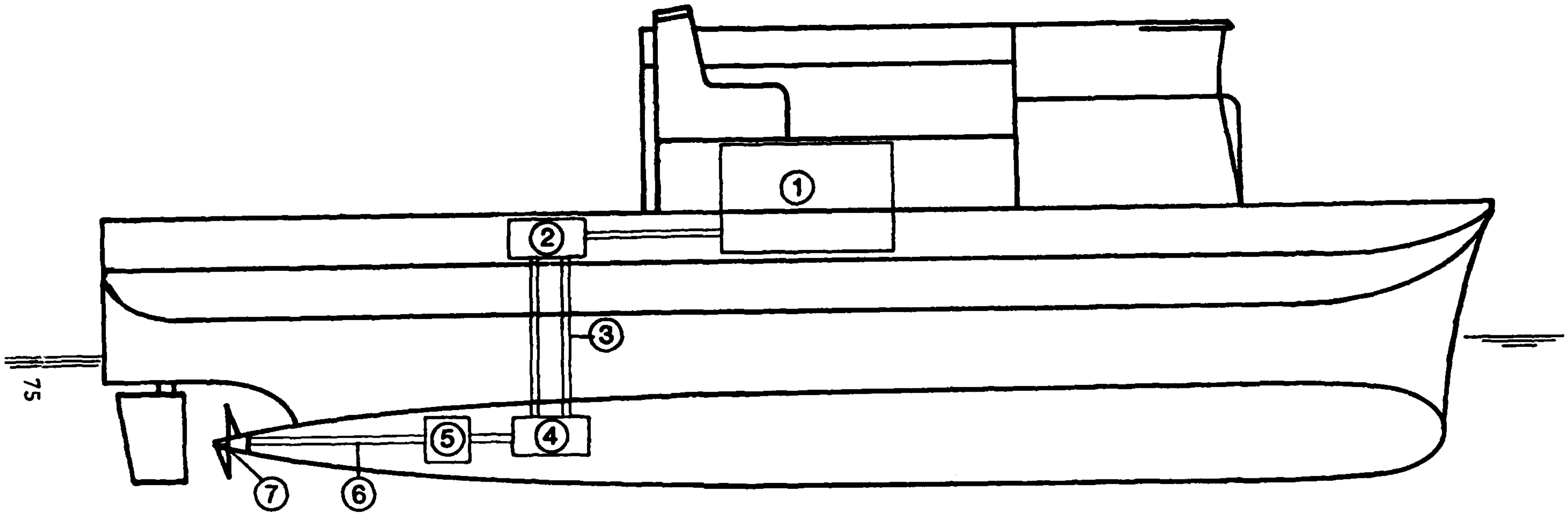


FIGURE 30 - **PROPULSION SYSTEM SCHEMATIC FOR SMALL SWATH SHIPS**

1 ENGINES

2 UPPER BEVEL GEAR BOX

3 TWIN VERTICAL DROP SHAFTS

4 LOWER BEVEL GEAR BOX

5 REDUCTION GEAR

6 PROPELLER SHAFT

7 CONTROLLABLE REVERSIBLE PROPELLER

placement examined, for a total of 16 propeller selections. Based on the selected propulsion systems and drive systems and the USCG missions, it was assumed that a controllable reversible pitch propeller (CRP) would be necessary. Propellers were selected from the subcavitating Gawn Series, and were assumed to be five-bladed propellers, [43]. Other criteria, such as cavitation criteria and hub to tip ratios, were selected in accordance with current USN practice, as demonstrated in the design of the DD 963 class ship. To remain consistent with data presented in Reference 41, a propeller diameter/lower hull diameter of 91% was chosen.

The BHP characteristics were determined from the resistance predictions obtained in the geometry initialization stage. A summary of the propulsive characteristics used is presented in Table 3. The full power design point was selected by using the optimum propulsive coefficient (PC), less one half of one percent, in lieu of performing a detailed trade-off of fuel and machinery weights. The partial power endurance fuel calculations were also made using the optimum PC for the given design speed, less one half of one percent to avoid making calculations at constant expanded area ratios (EAR) and at variable pitch. Finally, a constant transmission efficiency of 95% was assumed. The resultant BHP characteristics, as a function of maximum design speed and full load displacement, are presented in Figure 31. The requirements of the MESA 80 and SUAVE LINO are also included in Figure 31 to provide additional data points. It should be noted that this figure is plotted on a log-log scale.

TABLE III PROPULSIVE CHARACTERISTICS ASSUMED FOR THE FOUR CONCEPTS

NOTE: Values of relative rotative efficiency (rr), thrust deduction factor (1-t), and wake fraction factor (1-w) were assumed to be the same for all displacements.

Speed (kts)	nrr	(1-t)	(1-w)
10	0.96	0.91	0.875
15	1.02	0.90	0.850
20	1.025	0.93	0.920
25	1.01	0.90	0.945
30	1.015	0.915	0.970

Full Load Displacement	Speed (kts)	Propulsive Coefficient	PC-1/2%
125	10	0.666	0.662
	15	0.701	0.695
	20	0.738	0.733
	25	0.714	0.710
	30	0.729	0.725
250	10	0.693	0.689
	15	0.734	0.730
	20	0.730	0.726
	25	0.705	0.699
	30	0.721	0.717
750	10	0.719	0.715
	15	0.775	0.771
	20	0.720	0.716
	25	0.688	0.684
	30	0.711	0.707
1250	10	0.708	0.703
	15	0.775	0.771
	20	0.731	0.727
	25	0.682	0.677
	30	0.705	0.700

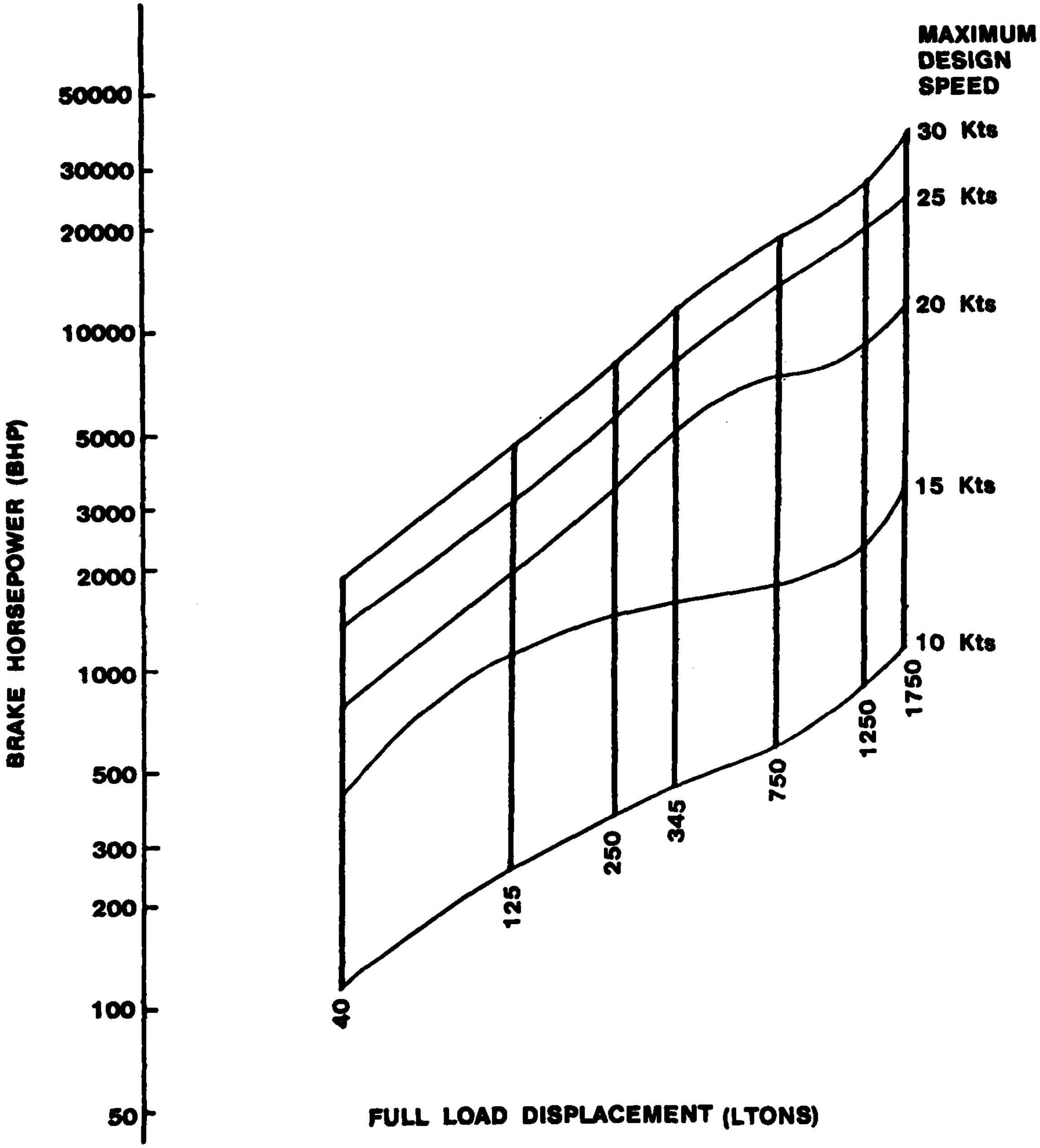


FIGURE 31 - **POWER CURVES FOR SMALL SWATH SHIPS**

Having determined the BHP requirements for the concepts, engine selection was begun. Several guidelines were developed for the engine selection, as follows:

1. When basic engine weights included the weight of the main transmission, 1/2 lb/hp was subtracted from the system weight to obtain an estimate of the base engine weight;

2. The minimum weight diesel delivering the required power would be chosen;

3. If four diesels were lighter than two, and delivered the same amount of power, or more, the four-diesel configuration would be chosen;

4. For gas turbine selection, only engine rating and thermal efficiency would be considered key factors;

5. If four gas turbines had the same efficiency, or higher, than two gas turbines at cruise speed, the four gas turbine configuration would be chosen.

Governed by these guidelines, a propulsion system of US diesels, European diesels, and gas turbines was selected for each of the displacements at four different maximum design speeds, as well as a combined diesel and gas (CODAG) system with a maximum design speed greater than 25 knots, making a total of 52 propulsion systems that were evaluated. A list of the engine selections made is presented in Appendix B.

Further assumptions were made in determining the weight of the propulsion systems, as follows:

1. Foundation weights for the gas turbine systems were taken as 40% of the total engine weight and included in the overall propulsion system weight;

2. Diesel system foundations were assumed to be of the compound (double elastic mounting) type with a mass of approximately 33% of that of the engine mass in order to attain proper structure-borne noise abatement, and were included in the overall weight of the propulsion system;

3. Although there would be some acoustic treatment applied to engine rooms, acoustic enclosure weights were not included in machinery weight, but have been considered in outfit weight;

4. Gas turbine intake and exhaust trunk weights included silencers, air filters, and moisture separators and were estimated to weigh approximately 2.2 lb/hp;

5. Diesel intake and exhaust trunk weights were approximated at 0.55 lb/hp;

6. Diesel system weights included a small factor for engine lubricating oil consumption. Gas turbine systems were assumed to have negligible lubricating oil consumption rates;

7. Fuel oil systems weighing about 0.35 lb/hp were included in propulsion system weights.

The drive systems and weights were developed to some detail including: engine, foundation, air supply, exhaust and fuel system weights; bevel gear and lower hull epicyclic gear weights, including foundations; drive shafting and propeller shafting weights, including foundations; bearings,

thrust bearings and foundation weights; and the propeller and associated hydraulic system weights. However, a detailed description of the design methods and assumptions for determining these various component weights is beyond the scope of this report. The weights obtained are included in the overall propulsion system weights.

Overall propulsion system weights, as a function of full load displacement, are plotted in Figure 32 for the US and European diesel systems at 20 and 25 knot maximum design speeds and CODAG systems at their particular maximum design speeds. Gas turbine systems are not shown because it quickly became clear that gas turbines alone were not viable options for small SWATH ships with the mission profiles desired. Their lack of suitability is a result of many factors including their inherently higher fuel consumption, intake/exhaust trunk volume requirements, and the discrete sizes of existing gas turbines.

Despite the lighter weight of gas turbine systems, which allows additional fuel to be carried, their fuel consumption characteristics still do not permit them to achieve the ranges attained by diesel propulsion systems. Furthermore, due to the nature of the USCG mission, which requires a large amount of time at cruise or loitering speeds, the gas turbine propulsion system would be required to operate frequently at less than full power output. The major benefit to be gained by using a gas turbine propulsion system is the maximum design speeds which can be obtained. These maximum speeds (in the range of 27-33 knots) cannot be duplicated by the heavier diesel systems without drastic range penalties. On the other hand, the major benefit of diesel systems is

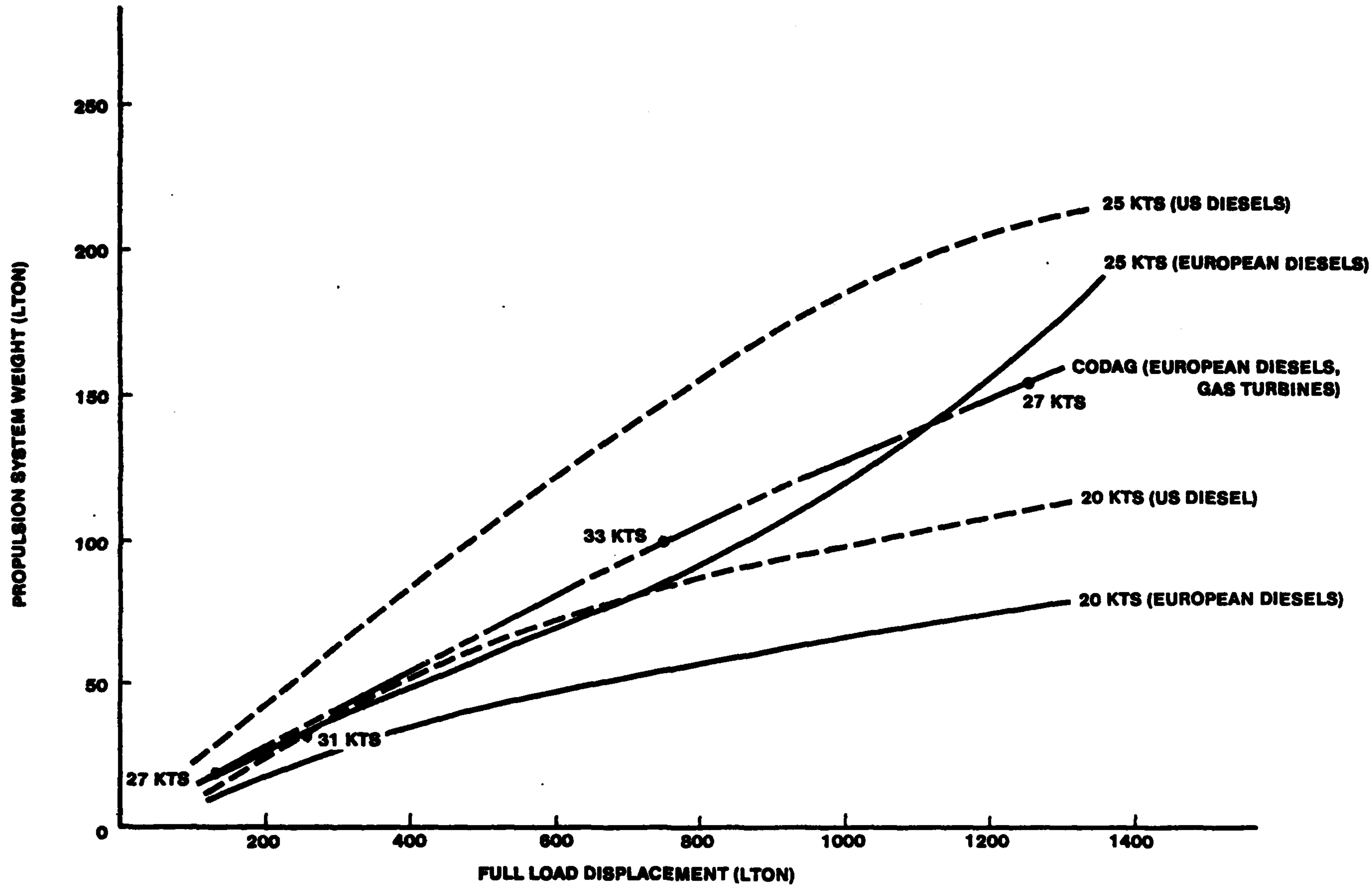


FIGURE 32 - **COMPARISON OF PROPULSION SYSTEM WEIGHT TRENDS FOR DIESEL AND CODAG SYSTEMS**

their superior fuel consumption characteristics at both full power and part power conditions which is sufficient to make up for their reduced fuel carrying capacity resulting from their heavier overall system weight.

The diesel propulsion systems considered in this study were medium and high speed diesels of both US and European manufacture. Fuel consumption characteristics, performance characteristics and to some extent, physical dimensions, though not identical, are similar between the US and European engines. From Figure 32, it is clear that the major difference between the two systems is overall weight. The European diesel systems are significantly lighter than the US systems, allowing more fuel to be carried, and hence a greater range. The drawback of the European diesels is the cost and possible reduced reliability and the concurrent increase in maintenance required. Availability of spare parts could also pose problems.

When examining maximum design speeds in the range of 25 to 35 knots, CODAG systems appear to offer great potential. The CODAG systems examined consisted of European diesels matched to gas turbines of sufficient power to provide the ship with a maximum design speed between 25 and 35 knots. CODAG systems can be justified by the nature of the USCG missions: since coastal missions require large amounts of time at slow to moderate speeds (5-20 knots), the diesel portion of the system could be sized to provide the power necessary for this speed regime at the maximum fuel economy possible; in the instances where higher chase speeds are necessary, the gas turbine portion of the system would also be used. There are, of course, some disadvantages to CODAG systems, the key one

being the much increased cost and complexity of the system. In addition, CODAG systems incorporate two types of technologies requiring spare parts and maintenance experience for both diesel and gas turbine systems. Finally, the CODAG system combines the weight and volume penalties of the gas turbine intake and exhaust requirements with the weight penalties of the diesels.

European diesel systems offered the best compromise of range and maximum speed for the four concepts investigated. Therefore, wherever possible, combined diesel and diesel (CODAD) propulsion systems using European systems were incorporated. A CODAD system includes four diesels, two for the low to moderate speeds and all four to attain maximum design speeds. Electric drive systems, driving into the proposed propulsion systems, could be used for very low speed operations. This possibility was not investigated in depth. There is more discussion on the selection of propulsion plants later in the "Range as a Function of Maximum Design Speed" section of this report.

ELECTRIC PLANT

The electrical power requirements for the proposed concepts were derived from the power installed in existing USCG vessels. In all cases, the kW estimates were substantially increased from the existing electric plants in order to accommodate the growing power requirements of today's shipboard equipment. The electric power requirements for these four concepts in comparison with the installed electric capacity of the ex-

isting USCG ships, are presented in Table 4. As seen in this table, large electric power requirements have been assumed for the SWATH concepts. These power requirements may have been oversized, in which case the estimated electrical system weight may be somewhat high.

Key assumptions made in the selection of electric plants are as follows:

1. Installed capacity would allow for a 30% service life growth;
2. Generators would not operate above 90% of their rating for any extended period of time;
3. Two units would share the electrical load;
4. The 24-hr average endurance load is assumed to be 75% of the specified load;
5. Engine thermal efficiencies would be governed by the same assumptions made for the propulsion system selection;
6. A generator efficiency of 95% would be assumed;
7. Since these concepts were considered to be "scaled-up" small craft, cable weights were assumed to be half those of larger conventional ships, approximately 90 lb/kW;
8. Lighting system weights were also assumed to be approximately half those of larger conventional ships, about 10 lb/ton.

The main engines for the electrical systems, as well as backup systems were chosen to be US diesels. Emergency backup units were only included in the 750 and 1250 LTON concepts, and were selected to be US gas turbines.

Electrical system weight is included in Figure 33, as a function of full load displacement. The rapid jump in the curve at approximately

TABLE IV ELECTRICAL POWER REQUIREMENTS

Existing USCG Vessels	Projected KW Need	Installed Generator Capacity (KW)*	Standby Generator Capacity(KW)
82'		40	0
95'		60	0
210'		400	100
270'		950	500
378'		1000	500
SWATH Concepts			
125 LTON	80	115	0
250 LTON	100	145	0
750 LTON	800	1155	225
1250 LTON	900	1300	225

* not including standby generators

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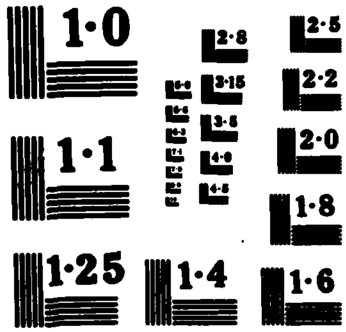

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

600 LTON is indicative of the increased mission capability of the larger ships. The fuel consumption of the electrical plants have been factored into range estimates for each of the concepts.

COMMAND, CONTROL, COMMUNICATION AND NAVIGATION EQUIPMENT

For completeness, command, control, communication, and navigation suites were postulated. The basis for the suites assumed were existing USCG ships, particularly the newest, the BEAR CLASS, [44, 45], and small coastal patrol craft, i.e., CPIC, [46]. In all cases, equipment was selected with the emphasis on systems already existing in USCG inventory. Since the USCG ships do not have extensive command, control, communication, and navigation suites, their weights have been included in the payload weights for this study. A list of the command, control, communication and navigation equipment assumed for each of the four concepts can be found in Appendix C.

AUXILIARY SYSTEMS

Auxiliary systems estimation was somewhat difficult because there is very little hard data on auxiliary system needs for small SWATH ships. Therefore initial weight estimates were made using algorithms derived for sizing auxiliary systems in planing craft, [30, 31]. The approach taken for auxiliary system weight estimation is not a standard USCG or USN ship design approach, but is more similar to that used in small

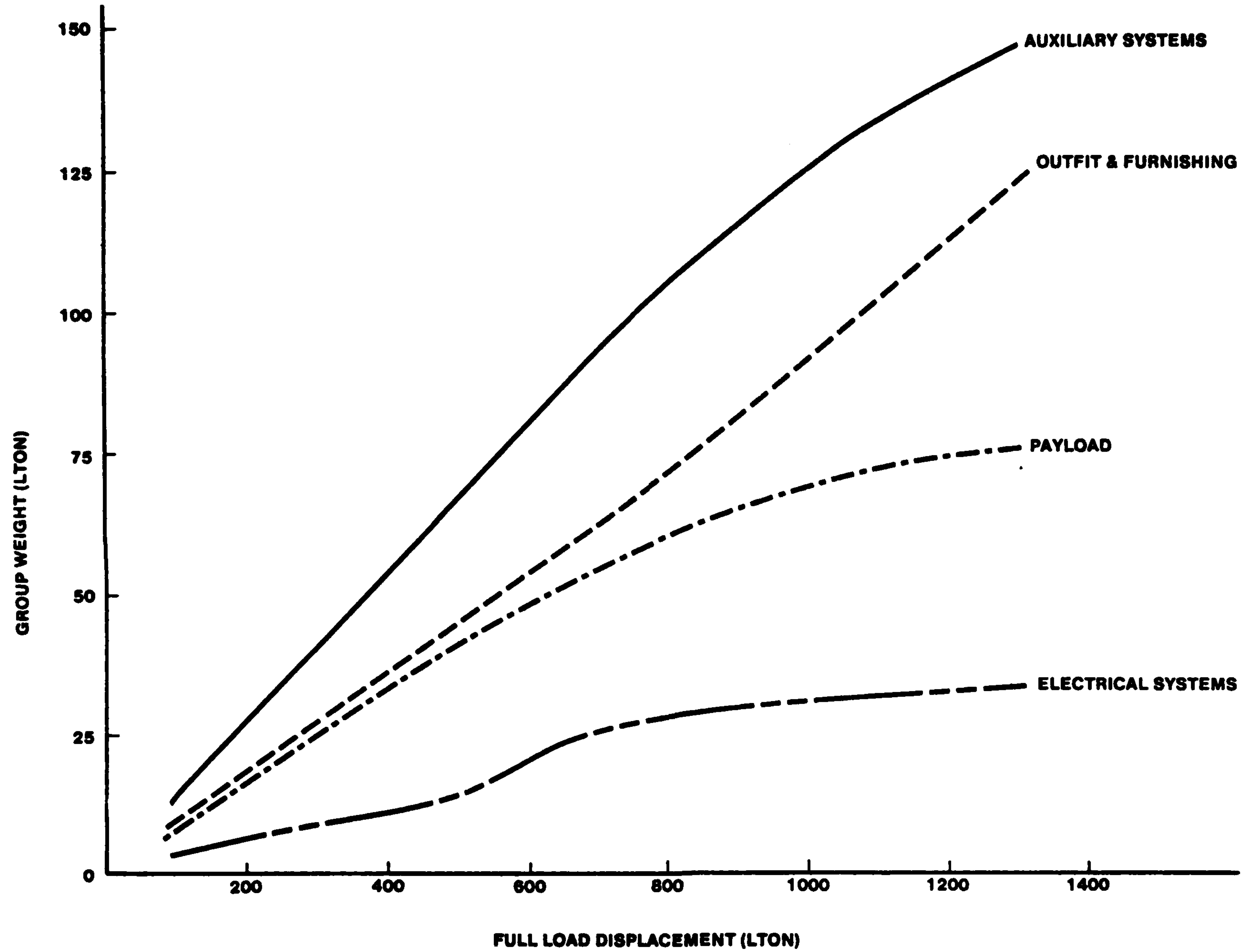


FIGURE 33 - **GROUP WEIGHT TRENDS FOR SMALL SWATH SHIPS**

craft design. This was felt to be reasonable because the four concepts examined herein are essentially small craft or outgrowths of small craft, but may entail some risk for the two larger concepts. The algorithm used provides estimates for auxiliary subsystems such as heating, ventilation and air conditioning (HVAC), refrigeration, plumbing, fire protection systems, drainage, ballast, fresh water systems, scuppers and deck drains, compressed air systems, distilling plants, steering systems, deck machinery, stores handling, replenishment at sea equipment, repair parts, and operating liquids. Weight estimates for each subsystem are dependent, usually, on the internal volume of the ship, crew size, or a specific physical dimension of the ship, whichever is most applicable to the particular subsystem. The empirical coefficients applied to each subsystem weight were, in general, derived from destroyer and destroyer escort data. Where appropriate, the equations have been modified to account for recent developments such as lightweight anchors and deck equipment.

After determination of the initial subsystem weights, each weight was examined for its applicability to SWATH ships and modified accordingly. Because of its twin hull aspects, the SWATH concept has greater auxiliary machinery requirements since many of the systems must be duplicated, e.g., steering systems, deck machinery and anchors. As a result, the weights of the steering gear, rudders, anchors, mooring, towing, and deck machinery were doubled. The planing hull algorithm also does not include motion control equipment such as forward canards, aft stabilizers and their associated control systems, which were included in the four concepts examined. As a result, these subsystems were account-

ed for separately. Finally, SWATH ships also require larger trim and ballast management systems than those required for planing craft. To provide the SWATH ship with some trim and draft control, one percent of the nominal full load displacement was allocated to liquid ballast, which increased the baseline ballast weight estimate by approximately a factor of four. It may be possible to use fuel as the ballast management system, but the authors preferred to use a separate water ballast system, so that the ballast tanks could be placed at the extremes of the concepts for more effective trim control.

Auxiliary subsystem weights of existing USCG ships were also examined to determine whether the USCG had any special auxiliary system requirements. Had any special requirements been found, they would also have been incorporated in the auxiliary system weight, but none were found for the concepts examined. A 10% margin was then added to the final estimate of the group weight. The final auxiliary system weights, as a function of full load displacement, including margin, are plotted in Figure 33. Not surprisingly, SWATH ship auxiliary weights tended to be somewhat higher than those of existing USCG ships, when compared on a displacement basis, mainly as a result of system duplication and the SWATH-specific systems.

OUTFIT AND FURNISHING

Outfit and furnishing weight estimates were determined in the same manner as were those for the auxiliary systems. Again, the algorithms,

originally intended for planing hull patrol craft, [30, 31], formed the basis for the estimates. Similarly, the weight estimation approach is more characteristic of small craft design than of standard USCG or USN ship design practice, and may entail some risk for the two larger concepts. The outfit and furnishing weights are largely dependent on the total internal volume of the ship and, to some extent, on the volume of particular spaces, as well as crew size and composition (officers, CPO, crew). The coefficients, again, are largely empirical and based on destroyer and destroyer escort data. Once more, where appropriate, the equations have been modified to include advances in technology, such as hull insulation to provide passive fire protection above the waterline. The outfit and furnishing subsystems estimated include: hull fittings; life boats, stowage and handling; ladders and gratings; nonstructural bulkheads and doors; paint and deck coverings; hull insulation; storerooms, stowage and lockers; equipment for utility spaces and workshops; food preparation and stowage spaces; living spaces; and medical spaces.

The initial outfit and furnishing weight estimates, based on the algorithm, were also individually examined for their applicability to the SWATH concept and adjusted accordingly. As a result of the large volumes in all four concepts, the weights of the nonstructural bulkheads and doors were increased substantially (at least tripled for each concept except the 125-LTON concept where it was increased by a factor of 2.5). In the 125- and 250-LTON concepts, the weights of the ladders and gratings were at least doubled. The weights for lifeboats, stowage and handling

were doubled for the 750- and 1250-LTON concepts. Finally, the estimates were checked against the weights of similar subsystems in existing USCG ships to find any special USCG requirements. The primary special requirement identified was the need to accommodate a crew comprised of both males and females and to meet the larger living space requirements of the USCG. As a result, the living space weights were substantially increased on the 750- and 1250-LTON concepts (up to 75%). The weights of the galley, pantry, scullery and commissary subsystems were also doubled on all four concepts to better compare with similar systems on existing USCG craft. A 10% margin was then added to the outfit and furnishings weight estimate. The outfit and furnishing weight estimates, including margin, are presented in Figure 33. SWATH ship outfit and furnishing weights also tended to be somewhat higher than those for existing USCG ships, when compared on a displacement basis. This is largely a result of the volume dependency of outfit and furnishing, and the greater volume/LTON of displacement value of the proposed SWATH concepts.

MARGIN POLICY

The margin policy used in this study does not conform to standard USN or USCG practices, but rather margins were individually applied by the authors to each weight group, depending on the detail to which the weight group was developed. Some weight groups were examined to a much greater degree of detail than is normally expected in conceptual or feasibility design stages, e.g., machinery and command, control,

communication and navigation subsystems. Throughout the study, effort was made to be conservative in weight estimates that would have the most effect on lightship weight; but a deliberate attempt was made to avoid compounding conservative weight estimates with conservative margins and thus stifling the concept. Existing or demonstrated conventional fast patrol boat technology was assumed for all subsystems, e.g., auxiliary machinery, outfit and furnishing, etc. No unconventional or beyond the state-of-the-art equipment was utilized. It is the authors' contention that the estimates used in this study are accurate representations of the characteristics each concept might have if they were constructed. A summary of the particular margins used in each weight group is as follows:

1. The method for estimating the structural weight was described earlier. Then, a 15% margin was added to the weight determined by the algorithm described to account for uncertainty and growth.

2. No margin was added to the propulsion system weight estimates because of the detail of the initial subsystem weight calculations. Throughout the sizing of the propulsion system, conservative powering coefficients and factors were assumed. In hindsight, a 9% margin should have been included based on small craft practice, [47], and would have been appropriate. However, these margins would not substantially change the results of this study.

3. There also was no weight margin added to the electrical system. This was a result of several factors, including the authors' feeling that they had greatly overestimated the required generator capacity (approximately 100% more than the electrical power installed on existing USCG cutters). A 30% service life growth margin was incorporated in selecting the generators.

4. Due to the detail with which the command, communication and navigation systems were estimated (Appendix C), no margin was included in this subsystem weight estimate. Again, in hindsight, a 12% margin, [47], might have been appropriate, but would have made little difference in the parametric study or the conclusions resulting from that study.

5. In estimating the auxiliary system weights, as mentioned earlier, an algorithm derived for planing craft was used as the baseline estimate and was then increased to meet the specific requirements of the SWATH concept and the USCG. To this, a 10% weight margin was added.

6. As with the auxiliary system estimates, the outfit and furnishing estimates were based on planing craft algorithms and modified to account for the uniqueness of SWATH ships and USCG requirements. To this final weight estimate, a 10% weight margin was added.

7. No margin was added to the armament system weights because of the small armament subsystems required on small USCG craft. A 5% margin might have been appropriate, if desired, but would have negligible effect on the outcome of the concepts examined.

8. In making range estimates, standard NAVSEA practice (DDS 200-1) was adhered to, including: a 10% increase in endurance power to account for hull fouling; a 24-hr average electrical load; and a 5% tailpipe fuel loss.

9. Neither accommodation margins, space margins, KG margins, nor specific future growth margins, except in the electrical system weight estimate, were included in the weight estimates for the four concepts.

It is the authors' opinion that these weight margins should be sufficient to include the uncertainties inherent in a new concept. However, careful weight control will be required in the construction of SWATH ships as they are very sensitive to weight growth.

Figures 34 through 37 illustrate the distribution of weight groups for each of the concepts. Note that the various subsystem margins have been included in each particular subsystem in these figures. Tables 5 and 6 summarize the distribution of the system weights for each of the four concepts, assuming European diesels which provide the maximum design speeds of 20 and 25 knots, respectively. In the case of these tables, the margins added to the individual subsystem weights have been

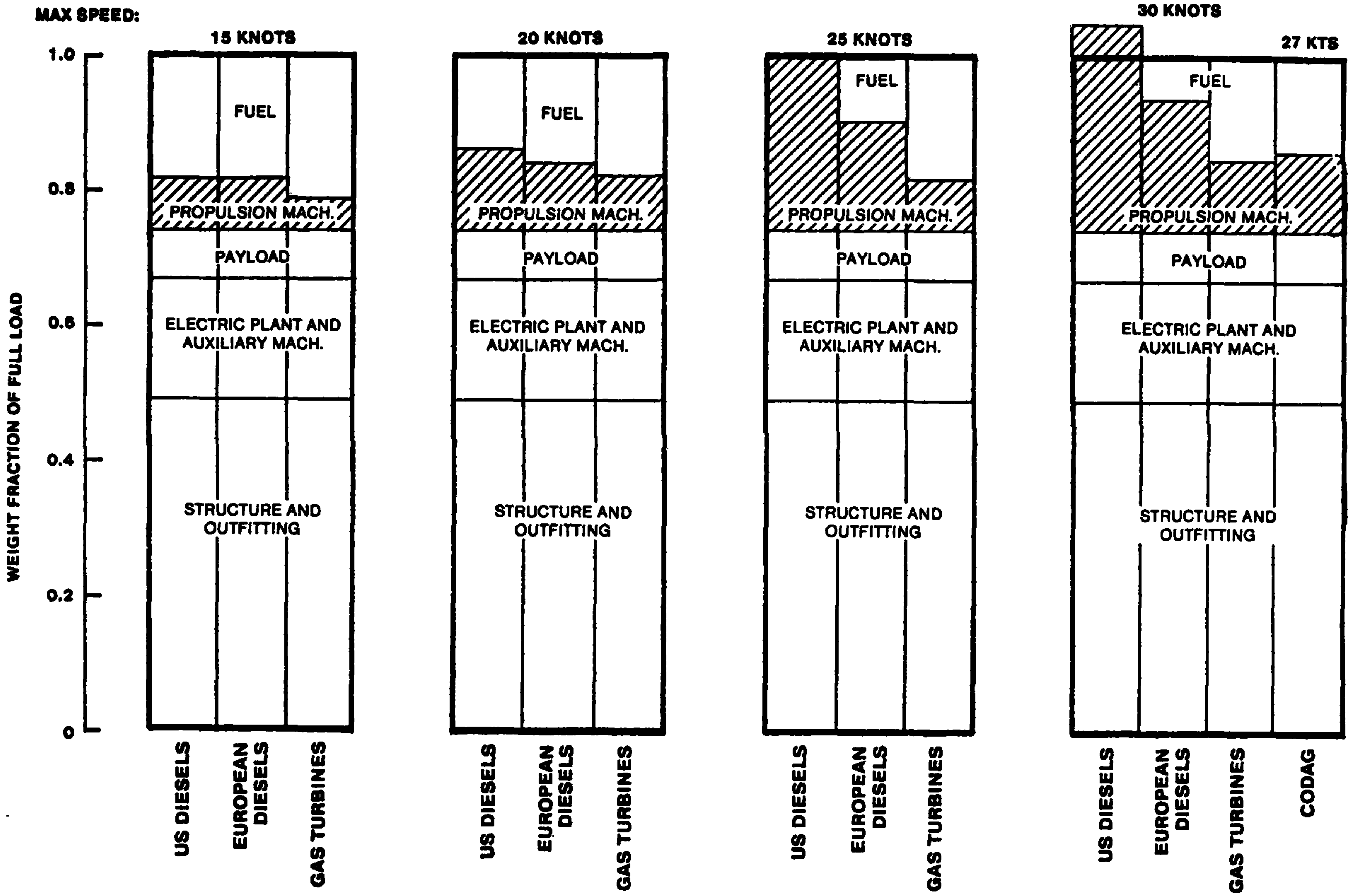


FIGURE 34 - **WEIGHT DISTRIBUTION FOR 125 LTON SWATH SHIP**

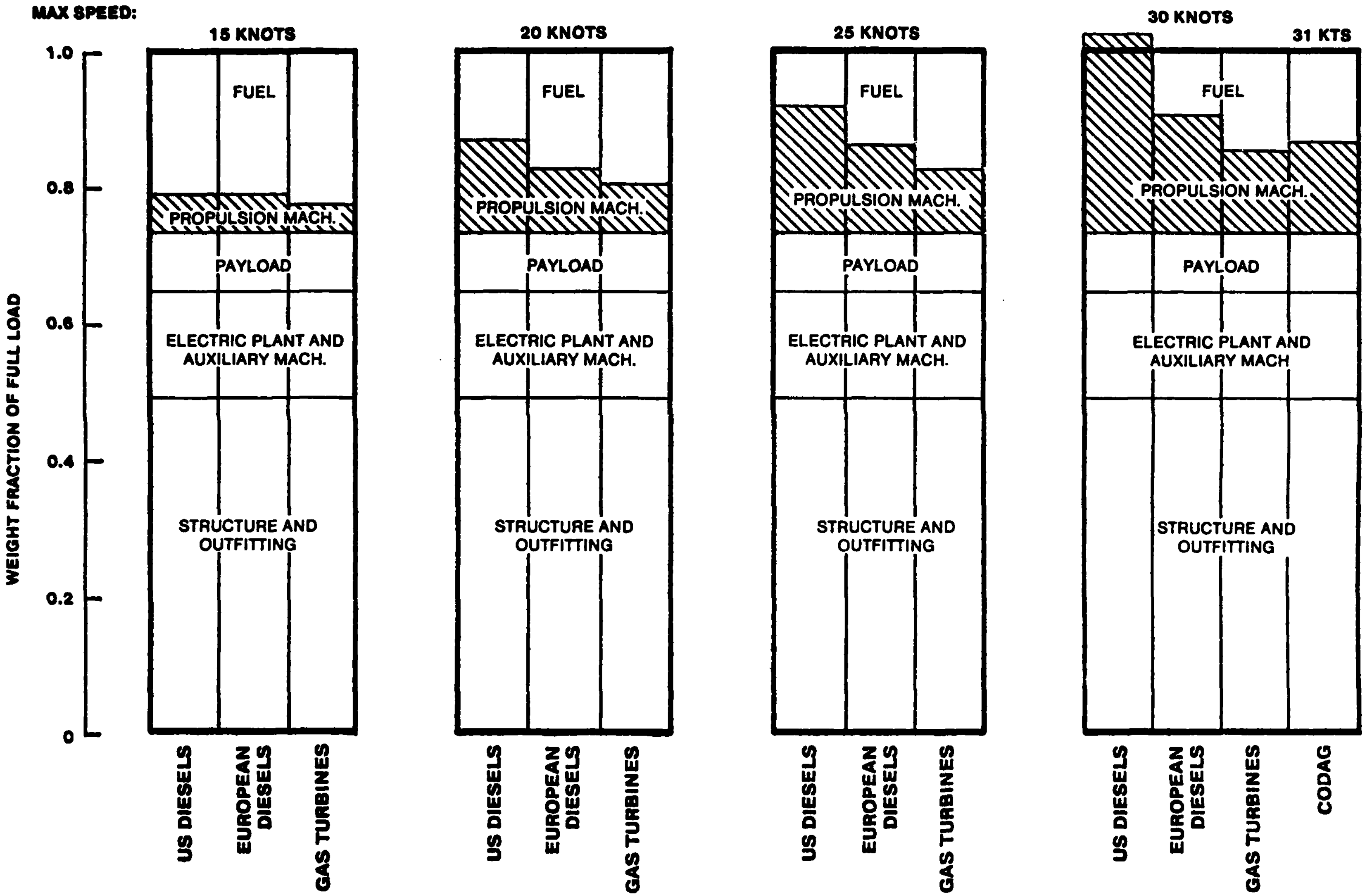


FIGURE 35 - **WEIGHT DISTRIBUTION FOR 250 LTON SWATH SHIP**

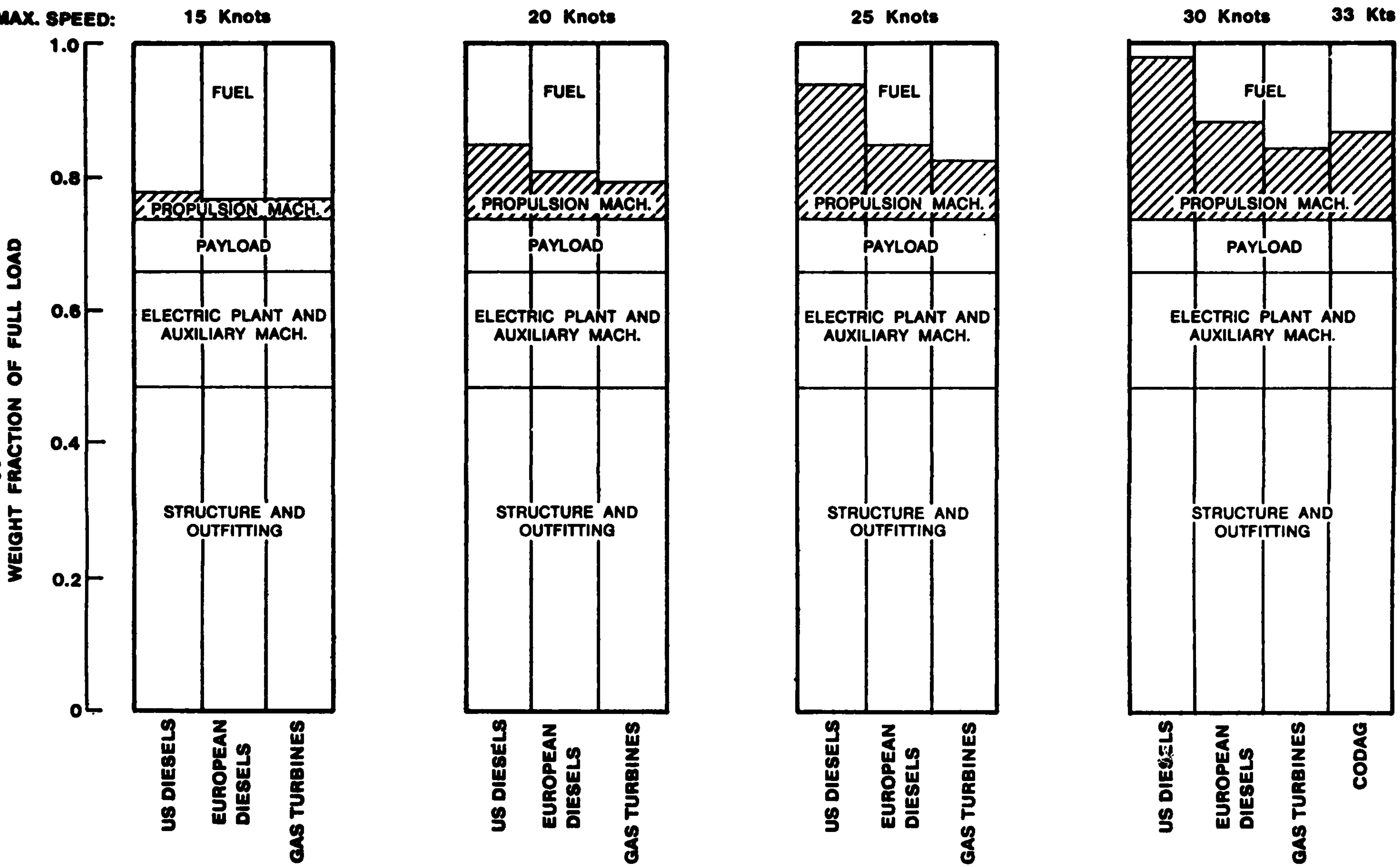


FIGURE 36 - **WEIGHT DISTRIBUTION FOR 750 LTON SWATH SHIP**

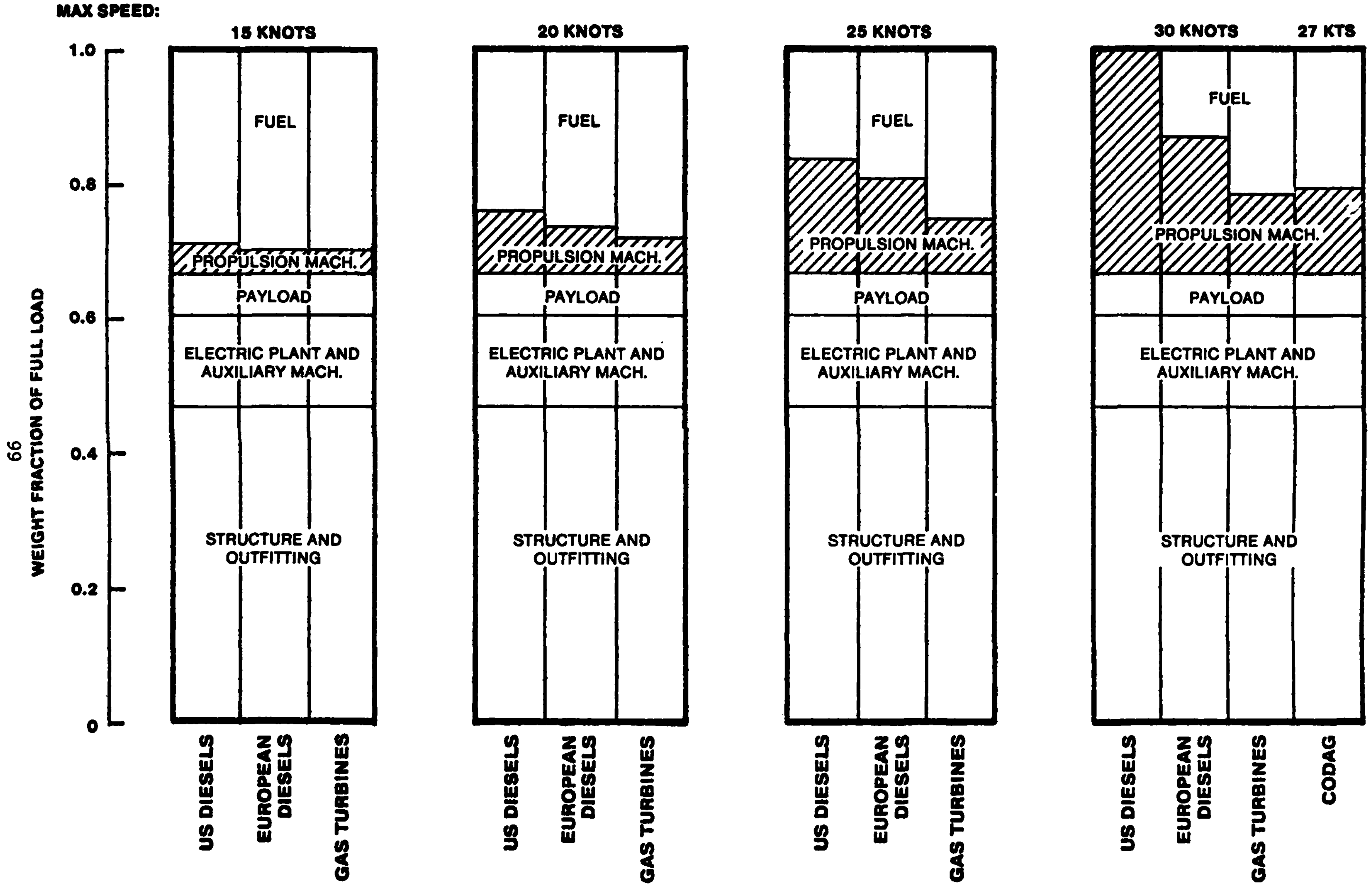


FIGURE 37 - **WEIGHT DISTRIBUTION FOR 1250 LTON SWATH SHIP**

TABLE V WEIGHTS FOR 20 KT SWATH CONCEPTS WITH EUROPEAN DIESELS

SWATH Concept:	125 LTON	250 LTON	750 LTON	1250 LTON
100 (Structure)	43.9	77.4	253.4	401.9
200 (Propulsion)	11.6	23.5	53.3	77.5
300 (Electric)	5.2	6.4	28.9	31.7
400 (Command)	1.9	4.4	9.4	15.6
500 (Auxiliary)	14.9	31.1	89.2	129.5
600 (Outfit)	9.9	27.5	60.4	93.5
700 (Armament)	0.1	2.4	2.4	7.3
LIGHTSHIP	87.5	172.7	497.0	757.0
MARGIN	10.4	20.3	60.3	109.3
LIGHTSHIP + MARGIN	97.9	193.0	557.3	866.3
Crew & Effects	5.5	11.9	29.7	41.1
Boats	4.0	4.0	4.0	4.0
Ammunition	0.5	1.9	1.9	3.0
Ship Fuel	18.0	41.0	147.0	327.5
Helicopter	0.0	0.0	3.4	3.4
Helo Fuel	0.0	0.0	8.0	8.0
Helo Stores	0.0	0.0	0.5	0.5
FULL LOAD	125.9	251.8	751.8	1253.8

TABLE VI WEIGHTS FOR 25 KT SWATH CONCEPTS WITH EUROPEAN DIESELS

SWATH Concept:	125 LTON	250 LTON	750 LTON	1250 LTON
100 (Structure)	43.9	77.4	253.4	401.9
200 (Propulsion)	19.4	30.8	86.3	167.5
300 (Electric)	5.2	6.4	28.9	31.7
400 (Command)	1.9	4.4	9.4	15.6
500 (Auxiliary)	14.9	31.1	89.2	129.5
600 (Outfit)	9.9	27.5	60.4	93.5
700 (Armament)	0.1	2.4	2.4	7.3
LIGHTSHIP	95.3	180.0	530.0	847.0
MARGIN	10.4	20.3	60.3	109.3
LIGHTSHIP+MARGIN	105.7	200.3	590.3	956.3
Crew & Effects	5.5	11.9	29.7	41.1
Boats	4.0	4.0	4.0	4.0
Ammunition	0.5	1.9	1.9	3.0
Ship Fuel	10.7	33.8	114.0	237.5
Helicopter	0.0	0.0	3.4	3.4
Helo Fuel	0.0	0.0	8.0	8.0
Helo Stores	0.0	0.0	0.5	0.5
FULL LOAD	126.4	251.9	751.8	1253.8

removed from the individual estimates and are presented as a cumulative lightship weight margin. If US diesels or gas turbine propulsion systems are desired, the Group 2 weight and Ship Fuel weights should be adjusted appropriately.

TRADE-OFFS AND PERFORMANCE

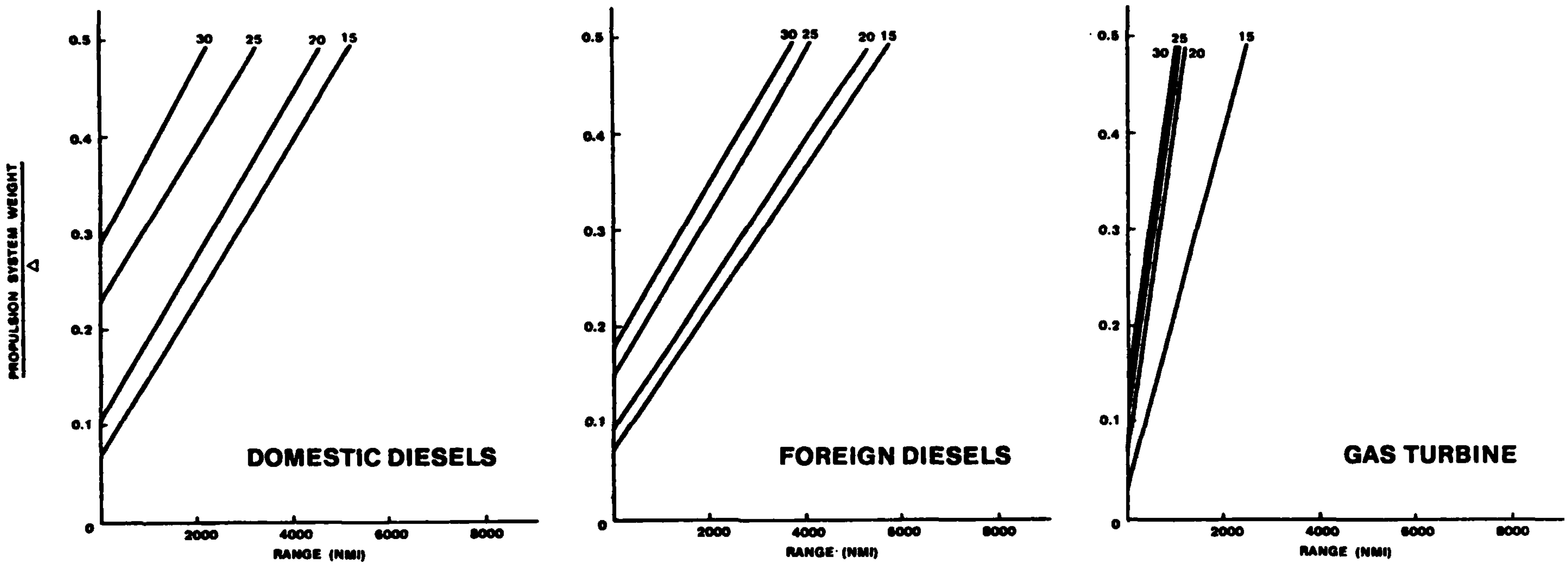
With the completion of the development of the four concepts, a foundation was completed from which speed, range, and endurance trade-offs and performance evaluations could be performed. It is felt that the four concepts developed provide a good basis for these trade-offs and evaluations. To the author's knowledge, at this time, there is no other small SWATH ship data base as complete as that developed for this parametric study. The following trade-off studies and performance analyses are an important part of this small SWATH ship data base and should provide a basis for evaluation of the SWATH concept for USCG mission applications, and for other coastal and small warship applications.

RANGE AS A FUNCTION OF MAXIMUM DESIGN SPEED

Assuming fixed displacements for each of the concepts investigated, the range versus maximum design speed trade-off is one of the most important. Figures 34 through 37 show that there is a direct relationship between the maximum design speed (hence propulsion system weight) and the amount of fuel that can be carried. The higher the design speed,

the heavier the propulsion system, and the less fuel that can be carried. When the specific fuel consumption characteristics of individual propulsion systems are factored into the analysis, the impact of maximum design speed on range can be examined directly. Figures 38 through 41 address this trade-off. These figures are plots of the propulsion system weight fraction plus a fuel load, as a function of range, for each concept using US diesels, European diesels, or gas turbines. It should be noted that in these plots, the propulsion system weight fraction includes all machinery, from the engine to the propeller and all machinery foundation weights. The fuel load assumed is that required to provide the indicated range. The individual curves represent ranges attainable by the propulsion systems listed in Appendix B. The ranges plotted are those calculated for the designated "best range" cruise speed, as determined from the resistance curves presented in Figure 11, and vary from 10 knots for the 125-LTON concept to 15 knots for the 1250-LTON concept. Propulsion systems with maximum design speeds of 15, 20, 25, and 30 knots were examined.

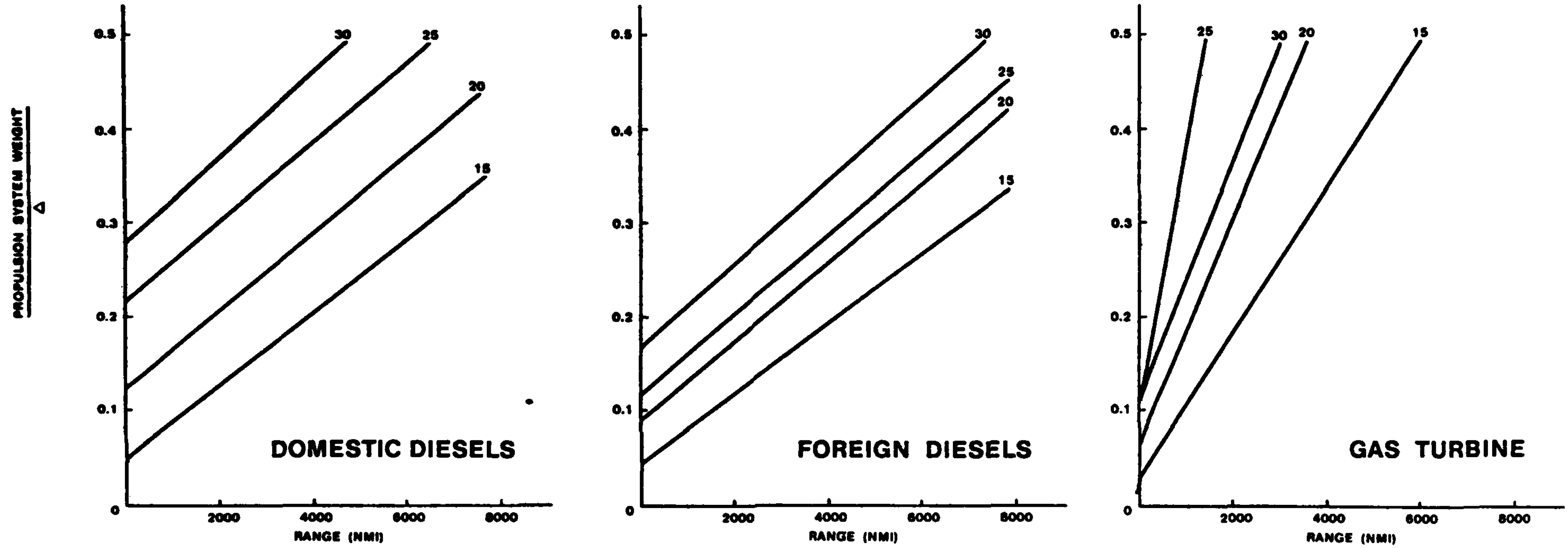
In figures 38 through 41 it is clear that on a range basis, gas turbine systems cannot compete with either type of diesel systems. This is a result of the notoriously high fuel consumption rates of gas turbines at both full power and part power conditions. The ranges attainable by high speed diesel systems, for both US and European systems, are summarized in Figures 42 and 43. Again, as in the previous plots, cruise speeds were assumed to be 10 knots for the 125-LTON, 12 knots for the 250-LTON, 13 knots for the 750-LTON and 15 knots for the 1250-



NOTES:

1. Propulsion system weight includes own foundation weights.
2. Curves represent specific propulsion systems of different maximum speeds.
3. Range calculated at sustained speed of 10 knots.

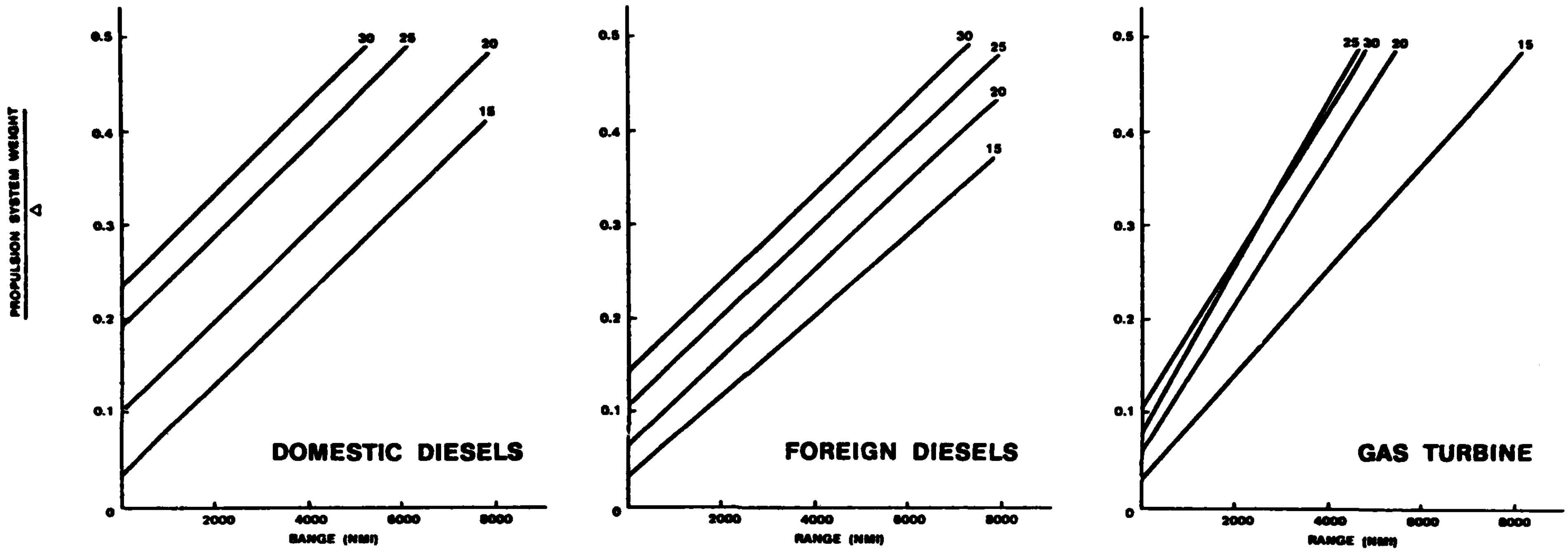
FIGURE 38 - **RANGE VERSUS PROPULSION SYSTEMS FOR THE 125 LTON SWATH WPB**



NOTES:

1. Propulsion system weight includes own foundation weights.
2. Curves represent specific propulsion systems of different maximum speeds.
3. Range calculated at sustained speed of 12 knots.

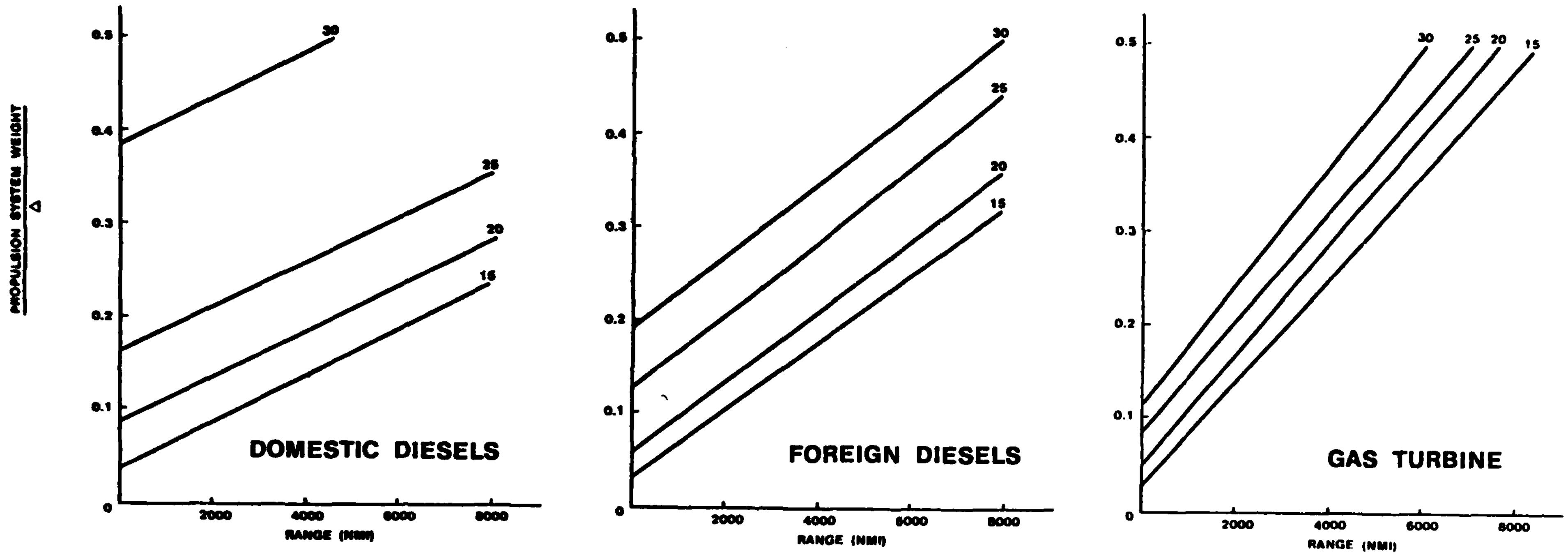
FIGURE 39 - **RANGE VERSUS PROPULSION SYSTEMS FOR THE 250 LTON SWATH WPC**



NOTES:

1. Propulsion system weight includes own foundation weights.
2. Curves represent specific propulsion systems of different maximum speeds.
3. Range calculated at sustained speed of 13 knots.

FIGURE 40 - **RANGE VERSUS PROPULSION SYSTEMS FOR THE 750 LTON SWATH WMEC**



NOTES:

1. Propulsion system weight includes own foundation weights.
2. Curves represent specific propulsion systems of different maximum speeds.
3. Range calculated at sustained speed of 15 knots.

FIGURE 41 - **RANGE VERSUS PROPULSION SYSTEMS FOR THE 1250 LTON SWATH WMEC**

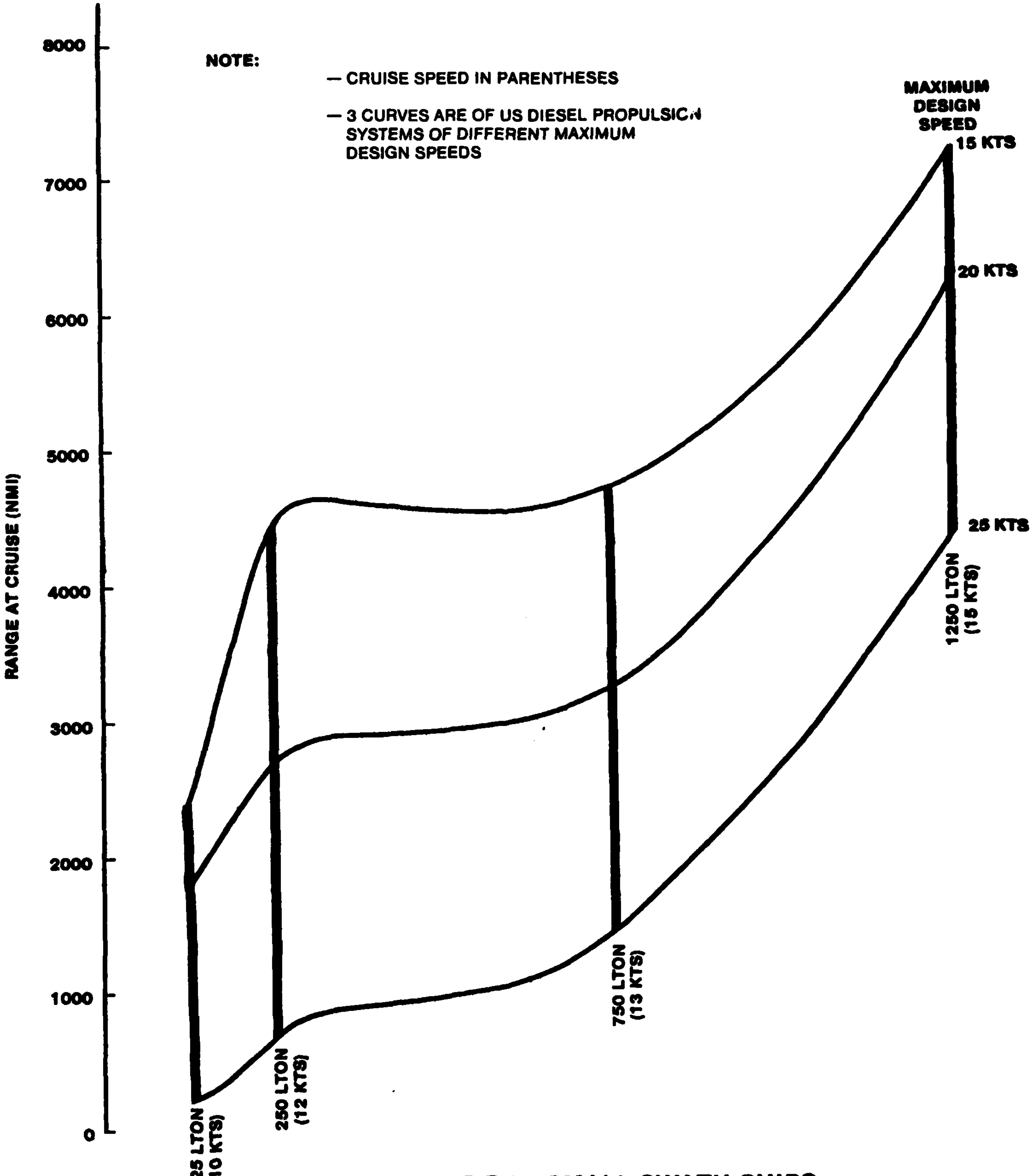


FIGURE 42 - **RANGE TRENDS FOR SMALL SWATH SHIPS WITH US DIESEL PROPULSION SYSTEMS**

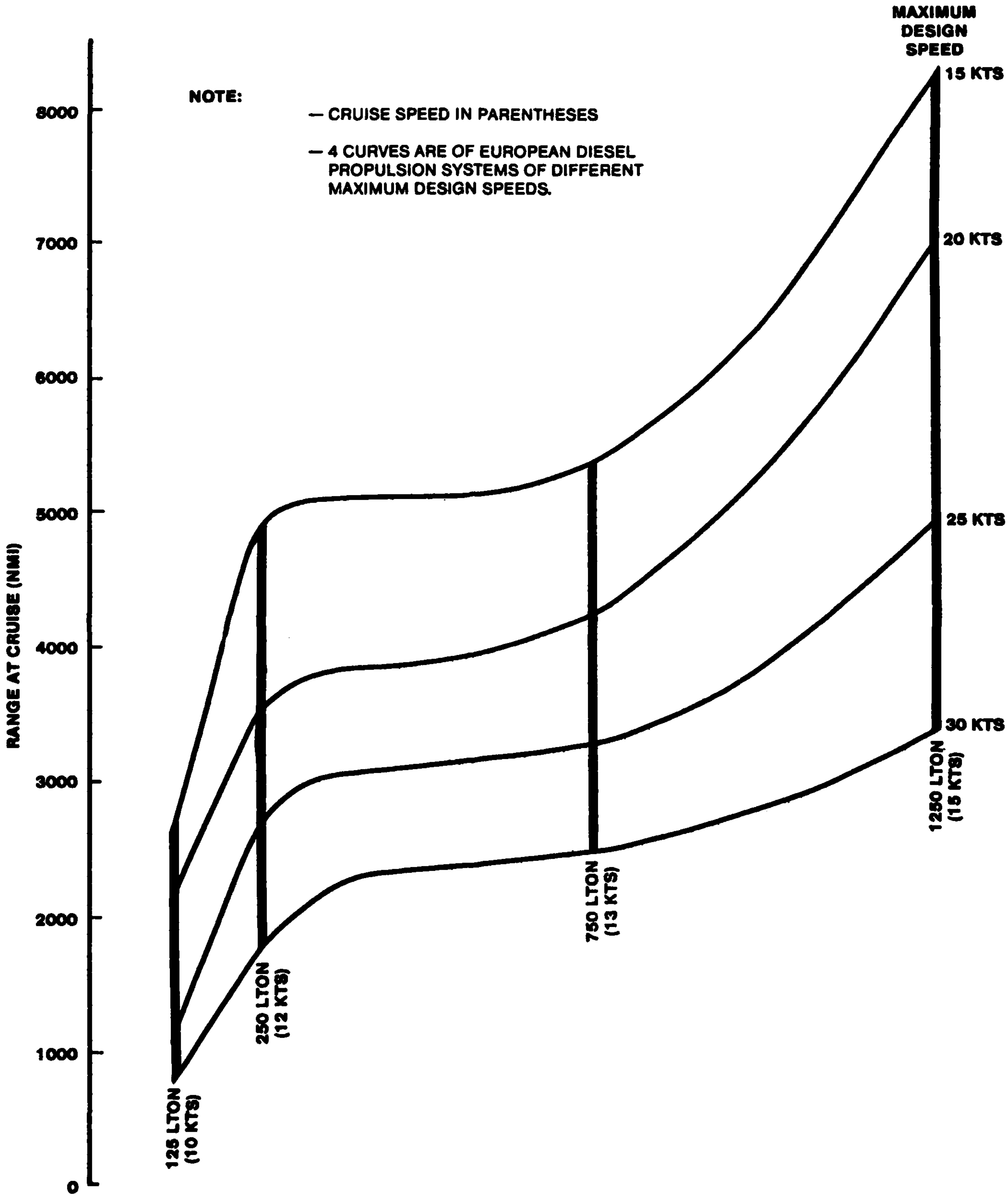


FIGURE 43 - **RANGE TRENDS FOR SMALL SWATH SHIPS WITH EUROPEAN DIESEL PROPULSION SYSTEMS**

LTON concept. The flat spot on the curve between 250-LTON and 750-LTON is a result of the additional weight of a helicopter system which results in the same amount of fuel being available, even though the ship displacement is increasing.

Figures 44 through 47 are summary plots of range as a function of maximum design speed for US and European diesels, gas turbines and CODAG systems. Several conclusions can be drawn from this set of figures. Again, gas turbine systems do not appear viable for small SWATH ships. US diesel systems with a maximum design speed of 20 knots allow, at cruise speeds, ranges roughly equivalent to those provided by European diesel systems with maximum design speeds of 25 knots. At cruise speed, CODAG systems are particularly attractive from a range basis because the cruise speed is attained by running only the diesel portion of the propulsion system. Ranges at maximum speed for the CODAG systems are roughly equivalent to those provided by foreign diesel systems, but, as a rule, at a higher maximum design speed.

The major conclusion drawn from the maximum design speed/range trade-off is that on SWATH ships high speed (greater than 25 knots) is attainable, but at a substantial cost in propulsion system weight fraction which reduces the subsequent available range. If longer ranges are required for a given concept they must be attained at the cost of the maximum design speed or a reduction in payload or an increase in ship size. As a result of this trade-off, the following recommendations are made for small SWATH ships configured for USCG missions:

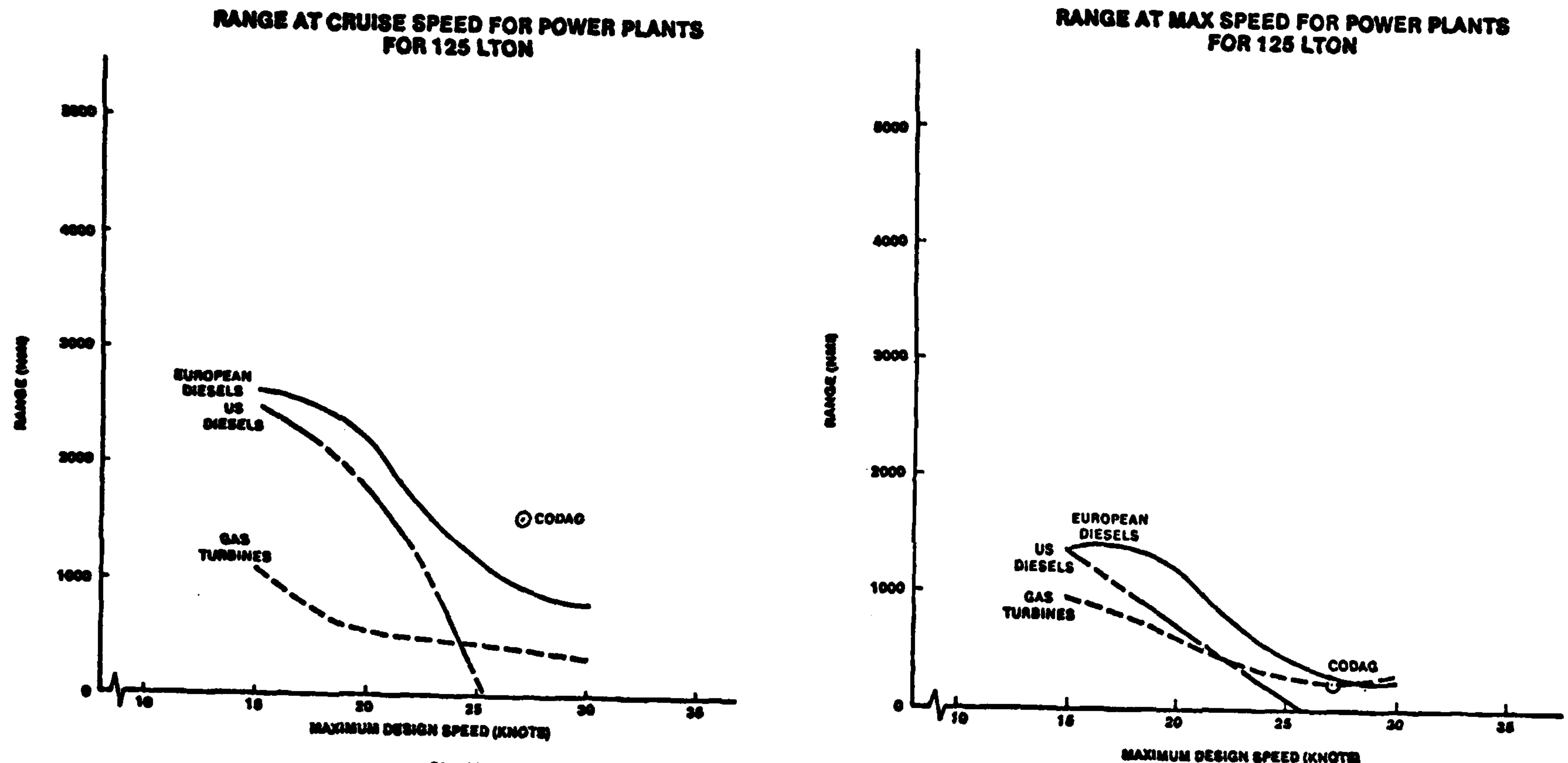


FIGURE 44

FIGURE 44 - RANGE AT CRUISE AND MAXIMUM SPEEDS AS A FUNCTION OF A SELECTED MAXIMUM DESIGN SPEED FOR THE 125 LTON CONCEPT

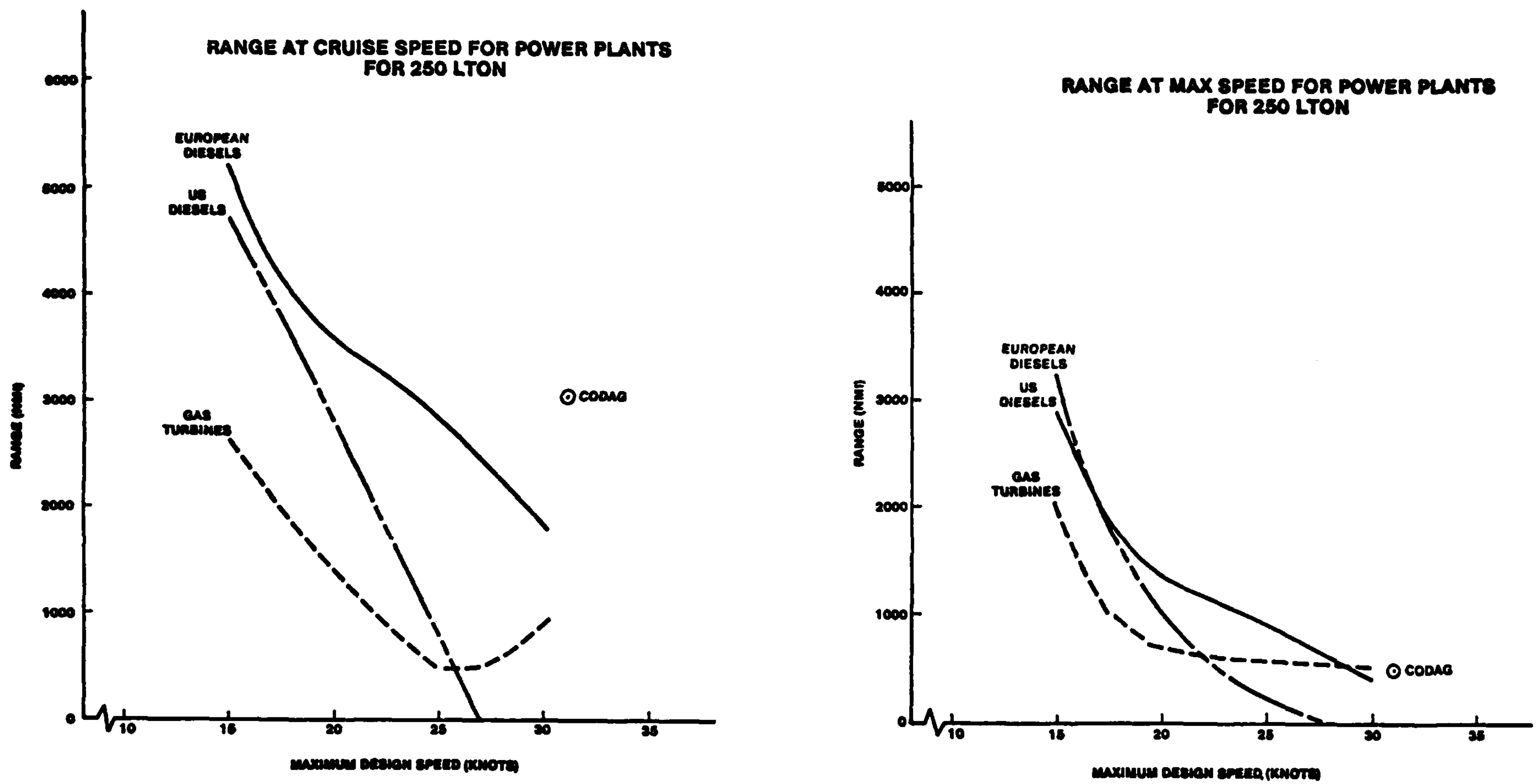


FIGURE 45 - RANGE AT CRUIS E AND MAXIMUM SPEEDS AS A FUNCTION OF A SELECTED MAXIMUM DESIGN SPEED FOR THE 250 LTON CONCEPT

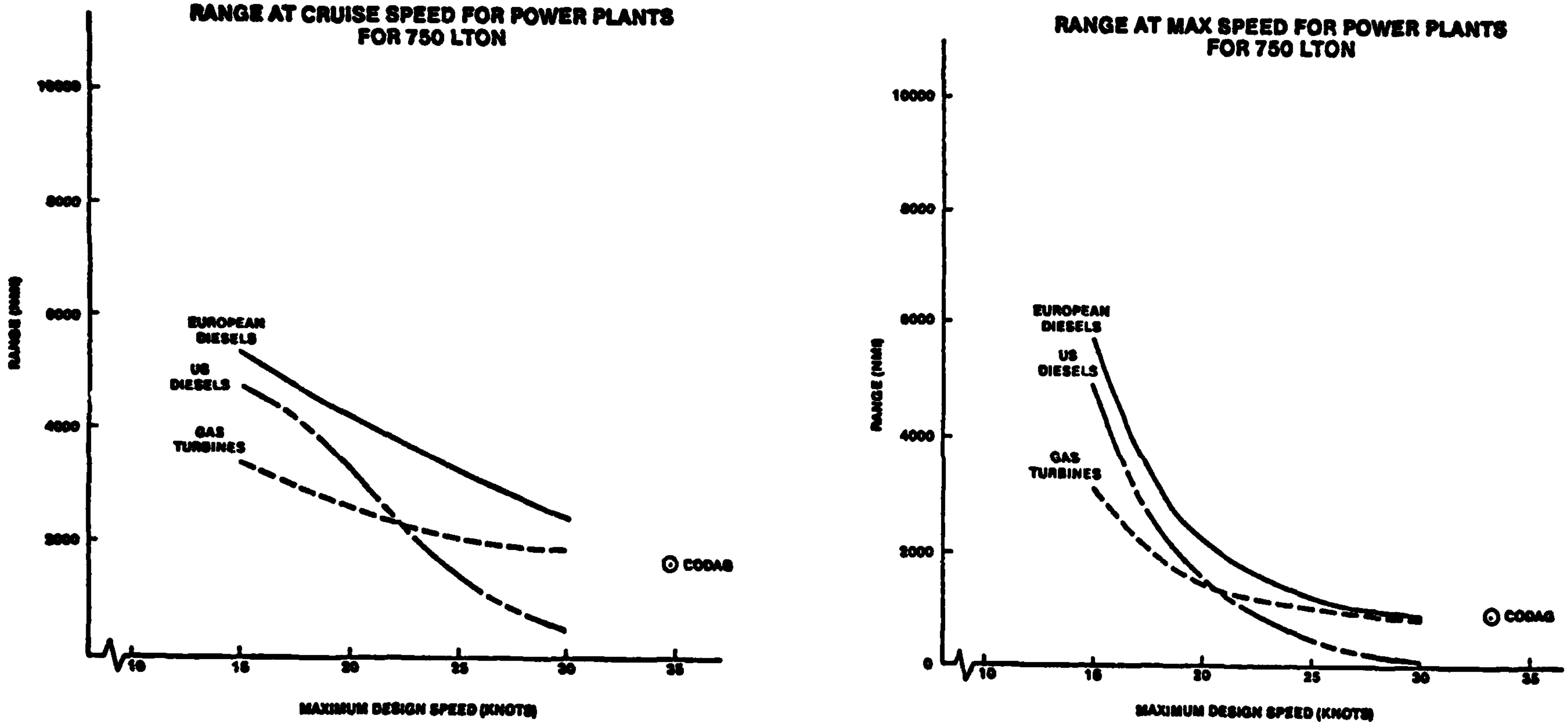


FIGURE 46

FIGURE 46 - RANGE AT CRUISE AND MAXIMUM SPEEDS AS A FUNCTION OF A SELECTED MAXIMUM DESIGN SPEED FOR THE 750 LTON CONCEPT

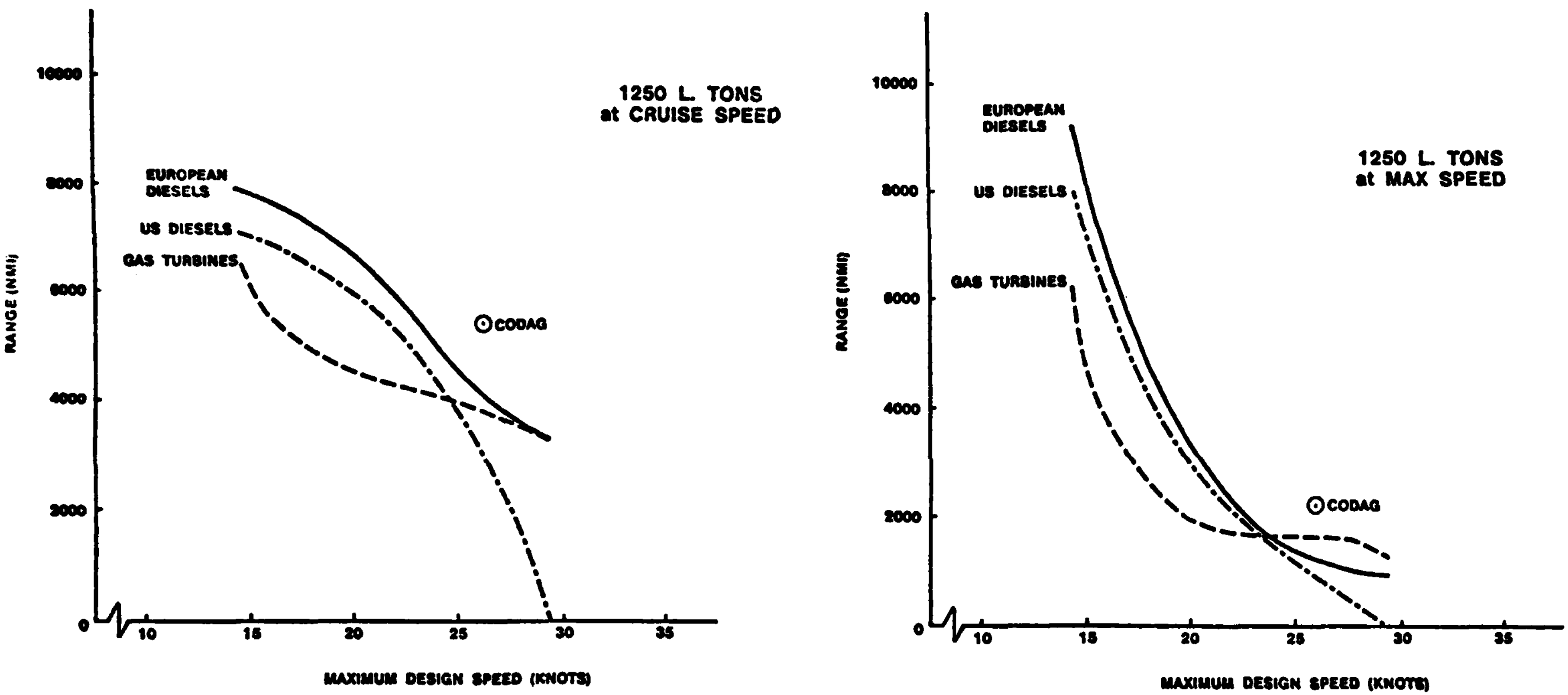


FIGURE 47 - RANGE AT CRUISE AND MAXIMUM SPEEDS AS A FUNCTION OF A SELECTED MAXIMUM DESIGN SPEED FOR THE 1250 LTON CONCEPT

1. Total gas turbine systems should not be considered;

2. If a maximum design speed of 25 knots is required, European high speed diesels should be considered, if a maximum design speed of 20 knots is sufficient, US high speed diesels may be satisfactory;

3. If a maximum design speed of 30 knots is required, CODAG systems appear to be a viable alternative.

TURNING AND MANEUVERING PERFORMANCE

Although no maneuvering analyses were performed, existing SWATH ships and past model tests indicate that SWATH ships are very directionally stable. This means that SWATH ships have very good coursekeeping characteristics, even on one propeller at slow speed, but are more difficult to turn at higher speeds. At slow speed, as a result of the widely separated propellers and a differential thrust capability, SWATH ships are highly maneuverable. In fact, they can turn 360 degrees, at zero speed, in their own length. In order to increase the turning moment of these four concepts, for turning at speed, the rudders were placed in the wake of the propellers. Also, dihedral forward canards have been included in an attempt to gain additional side force and hence additional turning moment at speed.

Turning and maneuvering characteristics in a seaway and in heavy weather may be different than the calm water performance described above. At low speeds, in heavy seas and high crosswinds, coursekeeping may be

somewhat difficult because of the large sail area of a SWATH ship, in combination with the reduced effect of its control surfaces. In an attempt to alleviate this problem, the sail areas of the four SWATH concepts have been minimized when possible. Higher speed turning and maneuvering characteristics should not be highly affected by sea or weather conditions. A good overview of the turning and maneuvering issues associated with SWATH ships may be found in Reference 48.

SEAKEEPING PERFORMANCE

An extensive, analytic seakeeping evaluation of the four concepts developed herein was performed, including a comparison of the predicted SWATH seakeeping motions with predicted motions for existing USCG patrol craft. The first step in this seakeeping evaluation was the collecting of existing full scale and model seakeeping data for both existing USCG monohulls and SWATH ships. A large amount of experimental data was found, approximately two dozen reports. This data was then examined for applicability to the intended purpose of the seakeeping analysis. The two dozen reports were eventually reduced to about a dozen reports because not all contained all the necessary information such as: significant wave heights, modal wave periods, ship headings, ship speeds, and consistent motion data. The remaining usable references were: for the SSP KAIMALINO, References 11, 16, 17, and 49; for the MESA 80, References 19 and 21; for the USCG 378-ft WHEC, References 11 and 50; for the USCG 270-ft WMEC, References 51 and 52; for the USCG 210-ft WMEC,

Reference 53; for the USCG 95-ft WPB, Reference 11; and for the USCG 82-ft WPB, Reference 54. At the time of this analysis there was no available seakeeping data for the SUAVE LINO. Since that time, some data for the SUAVE LINO has been published, [22]. Upon examination of the data contained in these reports, it was decided, because of the inconsistency in test conditions and method of data reporting, that seakeeping comparisons between the SWATH concepts and existing USCG monohulls would best be performed on an analytical basis, using the existing full scale and model data to validate the analytic data, where possible.

The analytic tools used for this seakeeping comparison were both developed at DTNSRDC. For the monohulls, the Standard Ship Motion Program (SMP), [55], was used. This program has been used previously to predict the motion responses of a model of the 270-ft WMEC. The results of this prediction, and their generally good correlation with the model test data can be found in Reference 51. This data, in turn, was used as part of the validation of SMP. The computer program used for the SWATH ship motion analyses was Ms. McCreight's SWATH ship sea-evaluation program already described in the "Geometry Initialization" section of this report. With both monohull and SWATH analyses done analytically, the evaluations could be done for identical test conditions, i.e., significant wave heights, modal periods, ship speeds and headings.

The sea conditions selected were determined by examination of USCG operating areas and available sea condition data. Sea conditions were chosen to represent the northeast coast of New England, south of Georges

Bank, in the North Atlantic, in the spring and fall. Also considered, were sea conditions off the Aleutian Islands in the Gulf of Alaska. The North Atlantic conditions were selected, even though the significant wave heights of the Gulf of Alaska were higher, because they offered a wide range of the modal wave (maximum energy) period and significant wave height combinations, which is important in examining SWATH seakeeping characteristics because of their modal period dependency. Significant wave height and modal wave period data were obtained from Reference 56. Appropriate "most probable" modal wave periods were found to range between 4.8 and 16.4 seconds. Only those modal period and wave height combinations which occur annually in the North Atlantic area more than 1% of the time were considered.

For both the monohull and SWATH ships, predictions of their root mean square (RMS) motion responses were obtained for pitch, roll, and heave at 10 and 15 knots and at 3 headings (head, beam, and following). These RMS values were then multiplied by a factor of 4 to obtain the significant (average of the 1/3 highest) double amplitude motions, in an effort to remain consistent with a large portion of the trial data. The resulting analytical data was then generalized into significant wave height bands, e.g. 5-10 ft. For each band, the median value was used as the representative significant wave height (e.g., 7.5 ft). Motion responses were calculated for the maximum, minimum and most cases was a great contribution to the parametric study.

The results of this analysis are presented in Figures 48 through 53, plotted as a function of significant wave height divided by the

cube root of the volume of displacement ($H1/3 / \nabla 1/3$), in a full load displacement condition. Each figure includes four plots for four different types of motions (pitch angle, roll angle, heave displacement, and heave acceleration at the CG) for similar conditions, i.e., similar heading and speeds. The curves on each plot represent the results of the analytical predictions for the most probable modal wave periods. The individual data points represent trial or test data. The abscissa was non-dimensionalized ($H1/3/ \nabla 1/3$) for these plots in an attempt to remove ship size effects from the data. With this normalization, data for the 378-ft 3000-LTON WHEC could be compared with data from the 82-ft, 75-LTON WPB and the 125-LTON SWATH concept. Data presentation in this format can possibly be misleading, since it is more difficult to tell what a particular ship's motion response is at a particular significant wave height. However, this manner of presentation does allow the comparison of monohull motions with SWATH ship motions, with some independency of displacement.

Previous testing has shown a great dependence of SWATH ship responses on modal period. This is not the case with monohulls, which are fairly insensitive to modal period. The examination of responses at many modal periods was an attempt to define the limits of SWATH ship results. The results were a wide scatter of motion responses. Once more it must be emphasized that the curves plotted in Figures 48 through 53 are the predicted ship responses at the median significant wave height and most probable modal wave period for that given band of significant wave heights. The analysis of ship motions and presentation of the re-

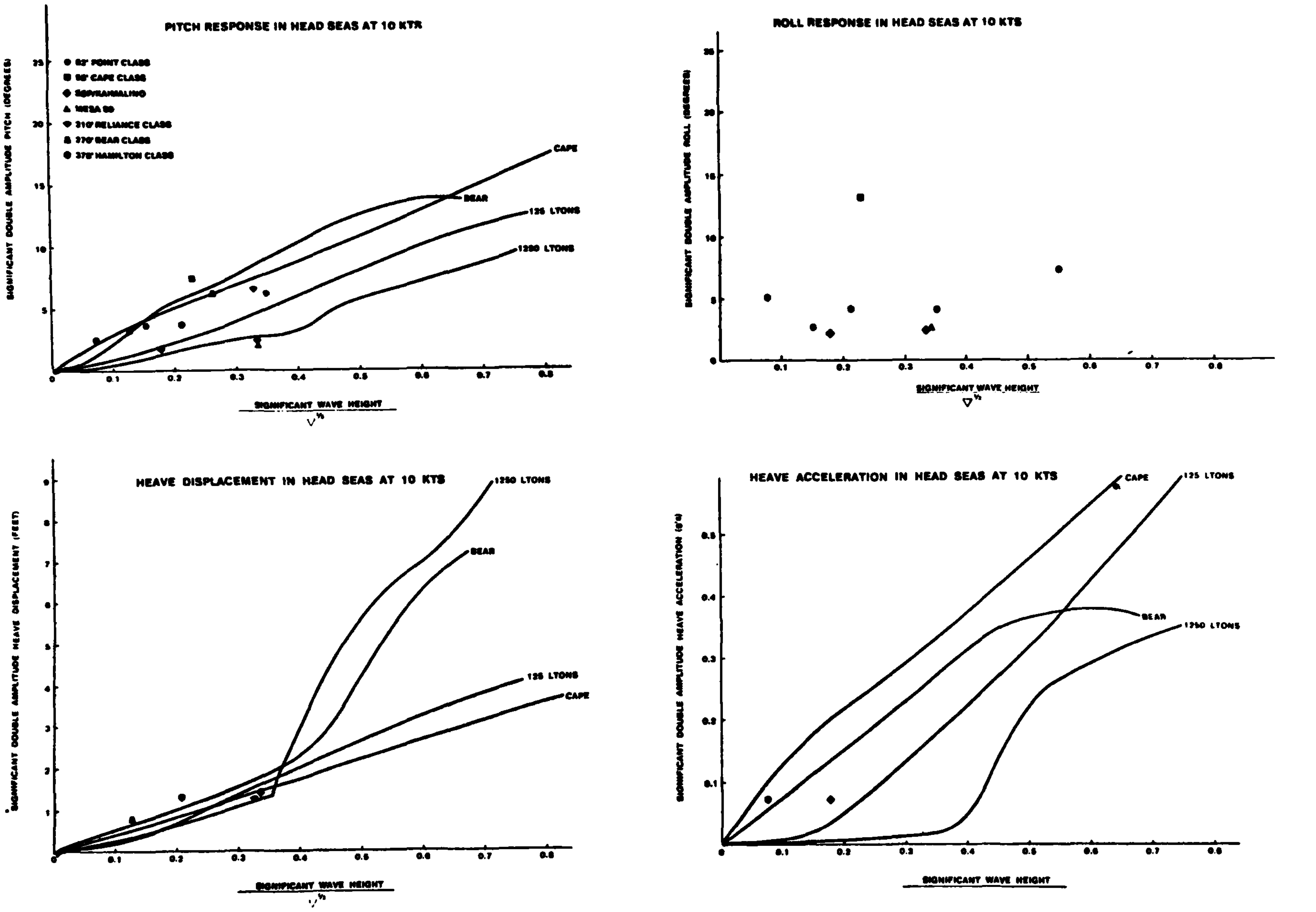


Figure 48 - Comparison of Seakeeping Motions of Existing Monohulls and the Four SWATH Concepts, Head Seas, 10 knots

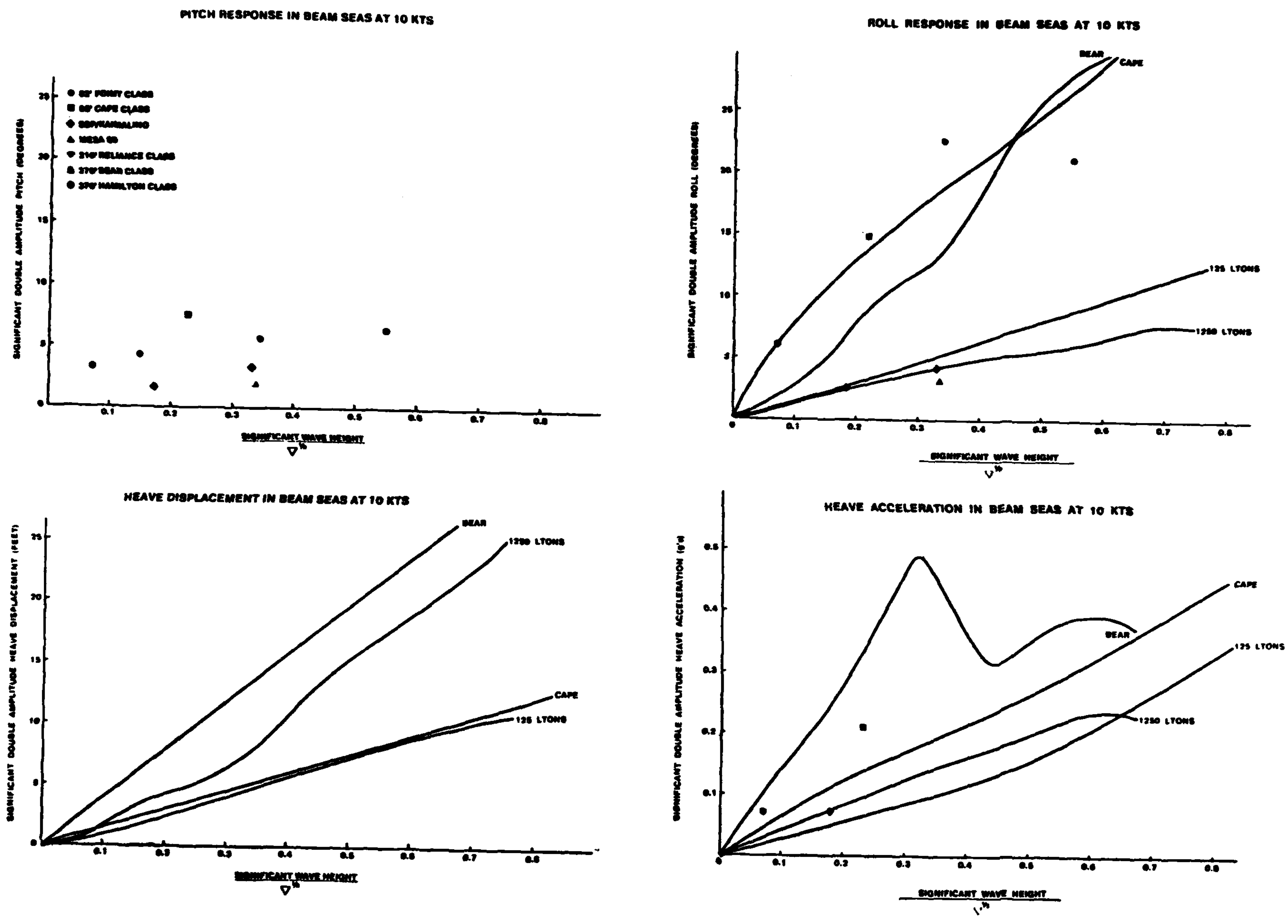


Figure 49 - Comparison of Seakeeping Motions of Existing Monohulls and the Four SWATH Concepts, Beam Seas, 10 knots

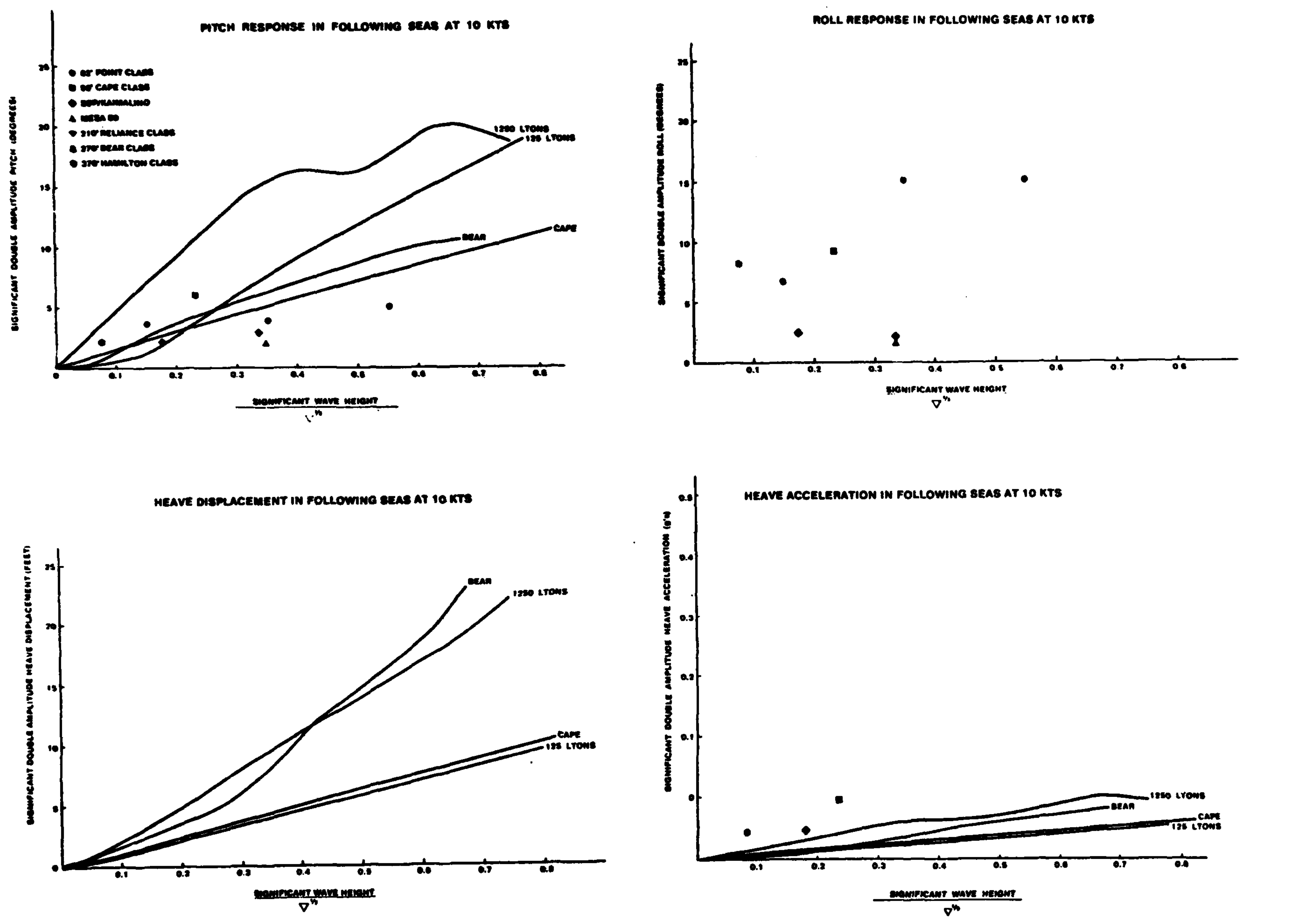


Figure 50 - Comparison of Seakeeping Motions of Existing Monohulls and the Four SWATH Concepts, Following Seas, 10 knots

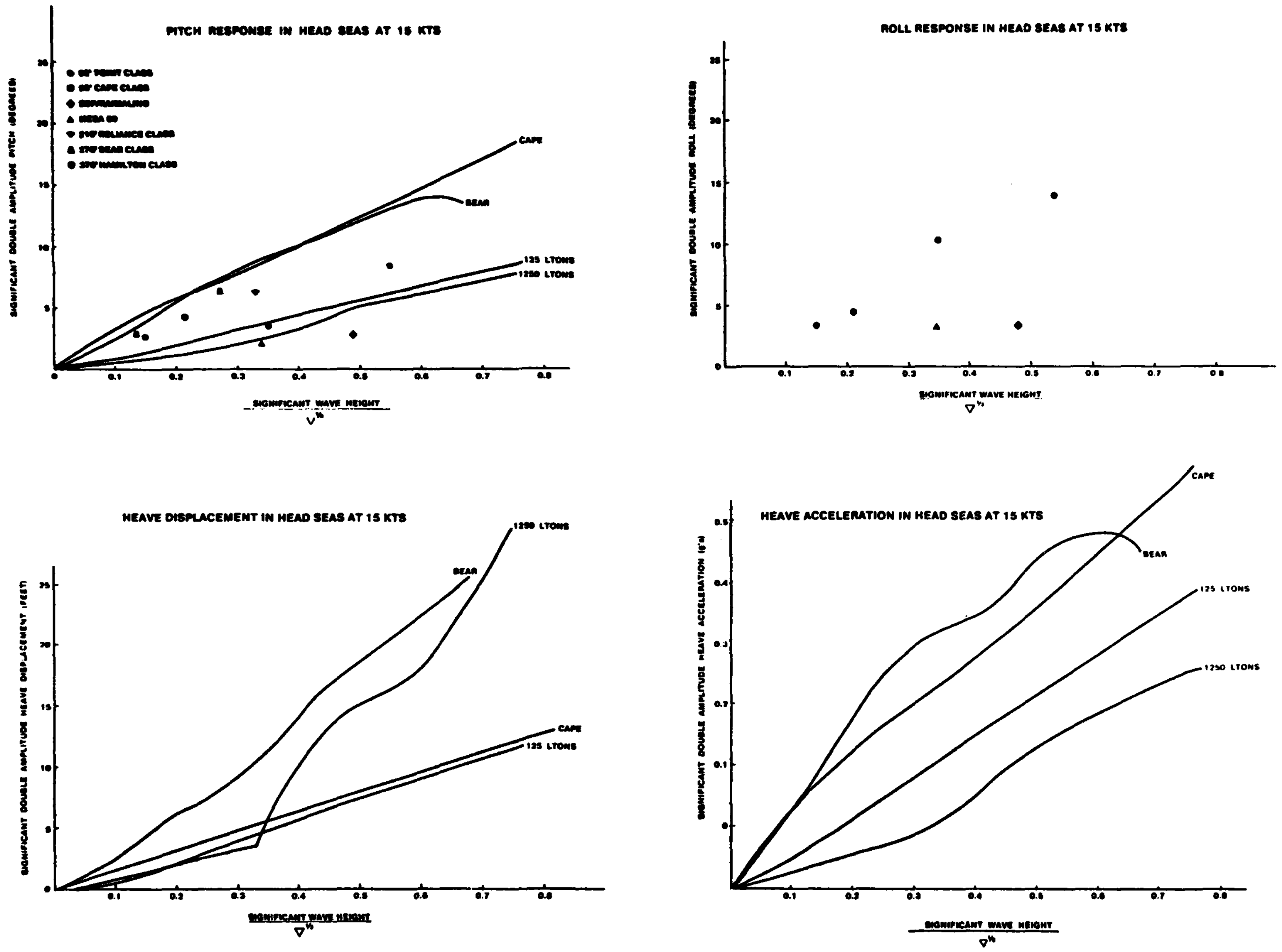


Figure 51 - Comparison of Seakeeping Motions of Existing Monohulls and the Four SWATH Concepts, Head Seas, 15 knots

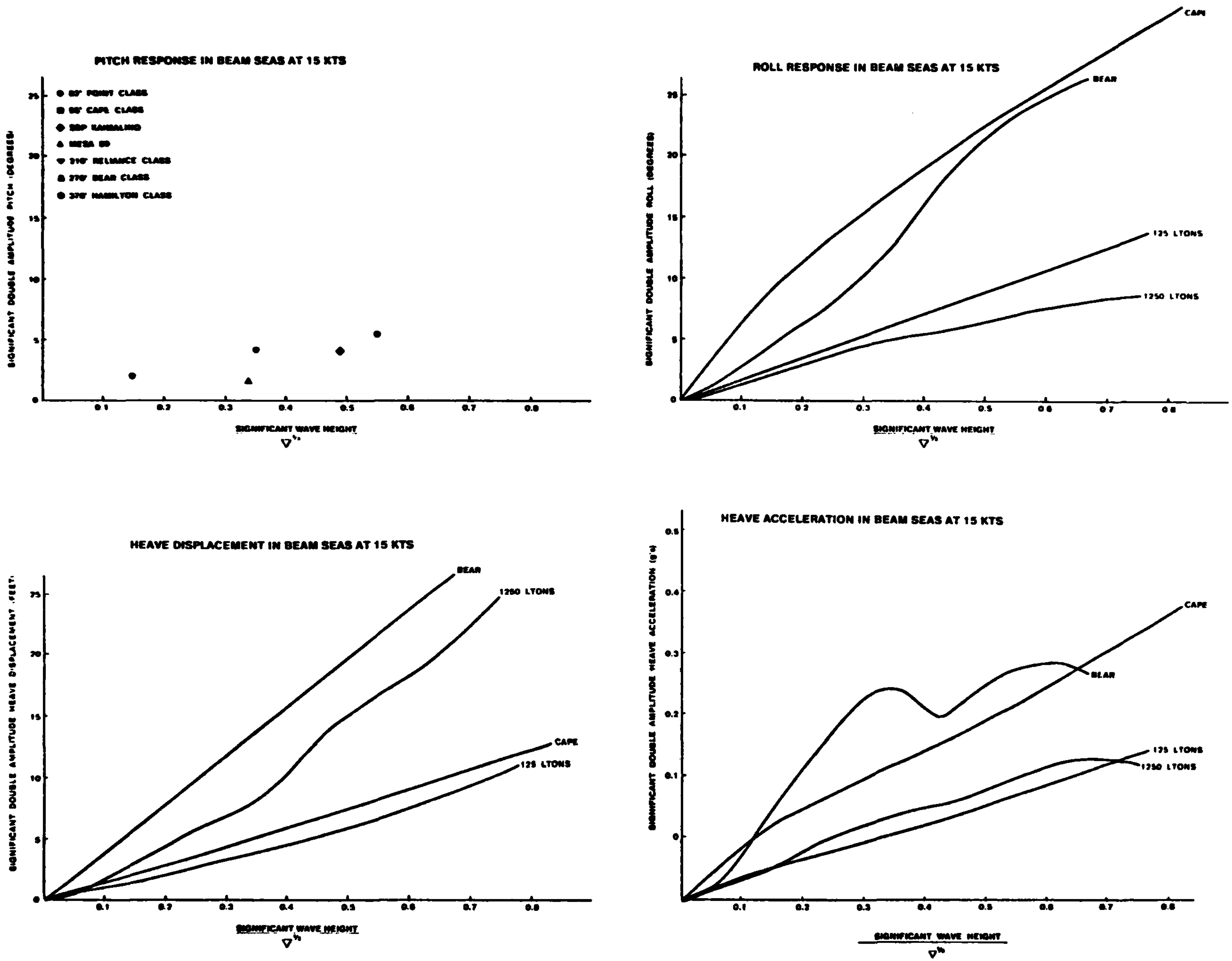


Figure 52 - Comparison of Seakeeping Motions of Existing Monohulls and the Four SWATH Concepts, Beam Seas, 15 knots

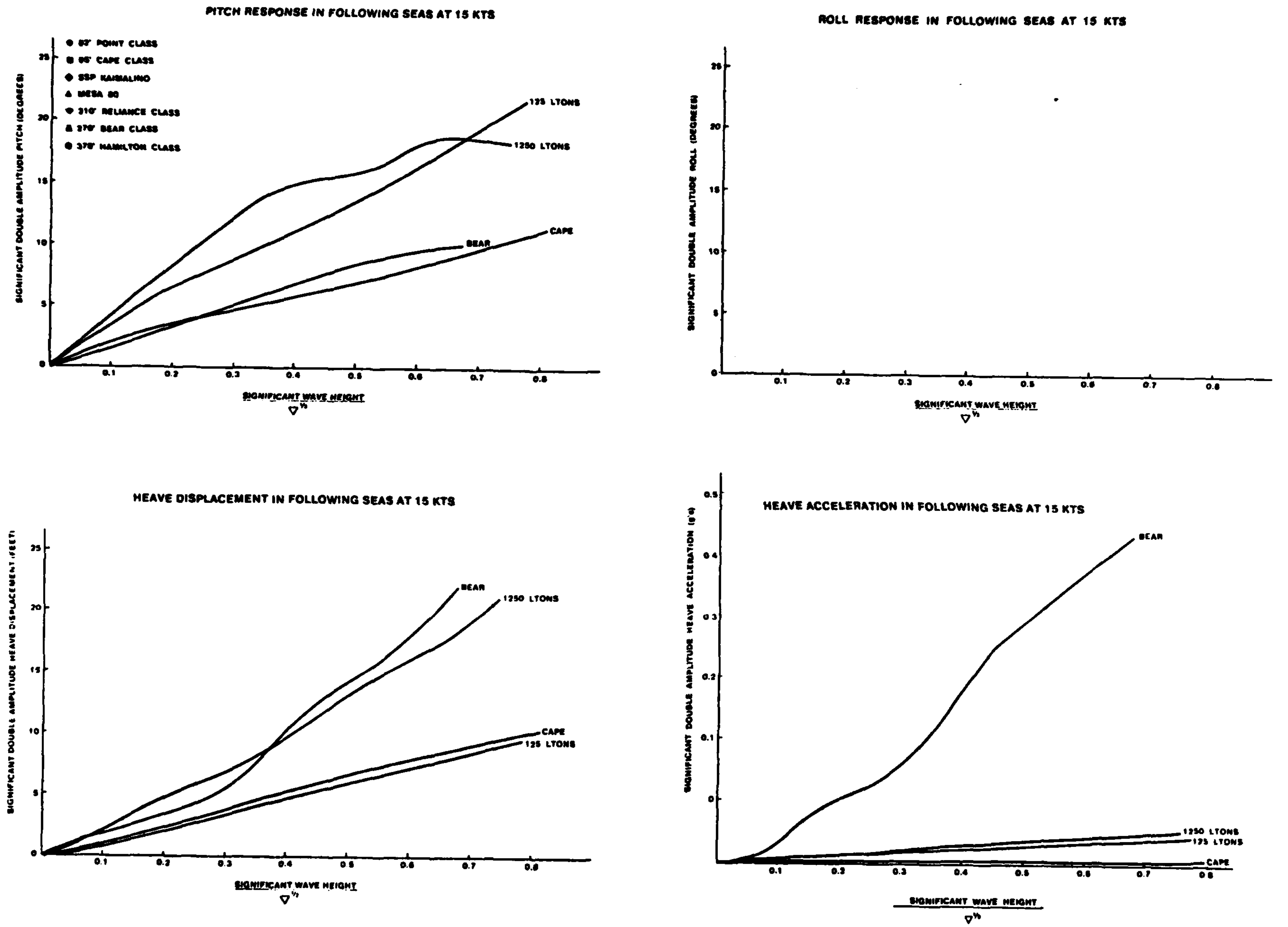


Figure 53 - Comparison of Seakeeping Motions of Existing Monohulls and the Four Concepts, Following Seas, 15 knots

sults in the maximum and minimum modal period and associated significant wave height conditions is beyond the scope of this report.

From Figures 48 through 53, it can be seen that most test and trial data were for pitch in head seas at both 10 and 15 knots, and for several conditions for which there was neither model nor full-scale data. Some of the predicted motion responses are not presented, for instance roll in head or following seas, and pitch in beam seas, because there is little roll predicted for strictly head or following seas and practically no pitch in beam seas. This does not correlate with the result of the full-scale tests done in seas which must have been somewhat bi-directional. The analytic data represents responses for the various ships in seas strictly in the given direction.

In general, the correlation between the computer analyses and the model or full-scale test data is satisfactory, especially for seakeeping predictions under the conditions just described. It is interesting to note that, in head and beam seas, for pitch or roll, there seem to be distinct bands of response. The SWATH ship responses comprise the lower band and the monohull responses, the upper band. In heave displacement, at all headings, the two bands formed are ship size dependent, instead of ship type dependent, the smaller ships having lower responses than the larger ships. The situation is reversed for the heave acceleration curves. In this case the higher band represents the motions of the smaller ships and the lower band the responses of the larger ships. The heave displacement curves in head seas at 10 and 15 knots show a

discontinuity in the 1250 LTON curve at about a significant wave height/ $\nabla^{1/3}$ value of 0.3. It is thought that this point is a result of the ship experiencing resonant heave displacement conditions.

SWATH ship vertical motions tend to have long periods, compared to the shorter periods of motions associated with monohulls. These longer periods allow onboard personnel more time to adjust to the changing ship attitude. The reduction in the accelerations should also reduce the amount of seasickness experienced by onboard personnel, [12].

The predictions for both monohulls and SWATH ships were made assuming some passive damping (bilge keels for monohull, where appropriate, and passive fins and canards for SWATH ships) on each ship type. The fins and canards on the SWATH concepts were sized by computer to ensure stability at speed by counteracting the Monk moment (a destabilizing moment) at the given maximum design speed. For this study, one set of passive fins was developed for each concept and used for all maximum design speeds. It should be noted that passive fins and canards are substantially larger than active fins and canards. The fins and canards shown in Figures 16 through 21 are active fins and canards, and are those that were assumed for the resistance predictions. Full-scale experience on the SSP KAIMALINO and SUAVE LINO show that, at speed, active control surfaces reduce ship responses by up to 50%, especially in head seas. Predictions based on similar computer analyses had indicated that the SUAVE LINO would have problems with bow motion in following seas. Full scale experience indicates no real problem of this nature. This is largely attributable to the presence of surge

in the full-scale ship and to the operation of the active control surfaces.

The general conclusion made, as a result of this seakeeping analysis, is that the seakeeping of the four SWATH concepts postulated is entirely satisfactory. The SWATH concept offers seakeeping characteristics equivalent to or better than those of the 378-ft, 3000-LTON, WHEC in sizes as small as 125 LTON. It is expected that the 125-LTON concept would be operational in a Sea State 6 and survive a Sea State 7. The other three concepts would perform even better in similar sea states. A limiting wave height analysis verified these conclusions.

The impact of this improved seakeeping capability is substantial. First, it allows mission satisfaction a greater percentage of time, particularly for ships operating in areas of frequent high sea state conditions. The seakeeping capability of the smaller SWATH ships allows them to perform SAR missions in high seas which could relieve the larger monohulls (1000 LTON and up) from having to perform these same missions. The improved seakeeping would also allow the SWATH concepts to make higher speeds in seaways than the existing monohulls which are forced to slow down due to slamming, deck wetnesses and intolerable motions. Reference 57 documents an analytical study showing the improvement in weapon and sensor accuracy resulting from the improved motion stability of SWATH ships. Further, these seakeeping characteristics have a major impact on the helicopter compatability of SWATH ships, allowing helicopter operations on ships of relatively small displacements. Finally, the improved seakeeping of SWATH ships should greatly enhance the morale

and efficiency of the crew. There should be less seasickness, the crew should be able to eat and sleep in a normal fashion, resulting in a more alert crew at the time of operations. The physiological portion of the USCG-sponsored side-by-side trials with the SSP KAIMALINO, [12], concludes, in part:

> "This finding shows that the benefits of crew adaptation to relatively mild vessel motion environments are not as great as the immediate and sustained benefits of inherently stable hull designs exemplified by the SWATH vessel."

All these factors have a synergistic effect, allowing smaller, hence potentially cheaper ships to perform the missions now being performed today by larger ships.

COST

Since few SWATH ships have been constructed, little hard cost data exists. All that can be said of the cost of construction is only conjecture until a SWATH ship is built. SWATH ships require more hull structure, but are probably more amenable to modular construction than monohulls. Hulls can be built somewhat independently of the struts, which in turn, can be built somewhat independently of the cross-structure, then the components can be assembled. For ships with more combatant-type missions, hull structure often is not a major portion of the total ship cost, the

main costs being the propulsion system and payload. In the case of ships configured for USCG missions this is not true. The USCG ships have, except for the helicopter (which may be as expensive as a small ship), largely, low cost mission equipment. The main costs of USCG ships are probably hull structure and propulsion system. With this in mind, the choice of propulsion system, and therefore maximum design speed, takes on added importance.

The duplication of many of the auxiliary systems and the increase in outfit and furnishing material probably also lead to increased cost. Therefore, a SWATH ship configured for USCG missions may be expected to be somewhat more expensive than a monohull of the same displacement configured for similar missions. But that additional cost buys substantially more operational capability than a monohull of the same size, especially in a seaway. Current USCG applications for their existing ships indicate that a small ship with excellent seakeeping characteristics, like those of the SWATH concept, may reduce operational costs and improve USCG mission capability. It is recommended that life cycle cost and potential mission capability enhancement be weighed against the possible greater costs of individual SWATH ship construction.

CONCLUSIONS

The general conclusions that can be drawn from this study are that small SWATH ships appear to be quite viable and capable when configured for USCG patrol craft missions. The trials which have been performed

on the few existing SWATH ships have demonstrated the ability of the SWATH concept to perform many of the tasks currently assigned to USCG patrol craft. Further, as a result of the superior seakeeping of the SWATH concept, small SWATH ships may be able to perform as capably as larger conventional ships when in a seaway. SWATH ships can be designed and built today using state-of-the-art technology commonly applied to fast patrol craft design and construction. The inherent area and volume characteristics combined with the excellent seakeeping of SWATH ships provide an excellent opportunity for putting helicopters to sea on small ships. In addition, the superior seakeeping can potentially permit real force multiplication due to impoved weapon and sensor performance, improved crew performance and morale, and improved operational capability under all weather conditions.

Other, more specific conclusions drawn from this study are:

1. SWATH concepts developed under the same criteria, of displacements similar to the four presented, but made of steel, are not as capable as those made of aluminum. A steel SWATH ship designed to match the capabilities of any of the four aluminum concepts presented, using the same design criteria, will be a 35-50% larger ship. It has not been proven which of the two similar-capability concepts would be more expensive - the aluminum or the larger steel ship, however, analytic cost models indicate that the aluminum concept would be less expensive because of the size growth in the steel concept.

2. Composite (aluminum and steel) cross-structures provide insufficient benefits to override the increase in complexity and cost.

3. Given the USCG mission requirements assumed (especially the required maximum speed and the required ranges), total gas turbine propulsion systems, because of their high fuel consumption rates, should not be incorporated in small SWATH ships as the prime movers.

4. If maximum design speeds of 30 knots or more are required, CODAG propulsion systems are recommended.

5. If maximum design speeds of 25 knots are acceptable, a European high speed diesel propulsion system is recommended.

6. If maximum design speeds of 20 knots are acceptable, a US diesel propulsion system is recommended.

7. For SWATH ships in the size range examined, Z-drive transmission systems appear desirable and are within the state-of-the-art of transmission technology.

8. Auxiliary systems and outfit and furnishing group weights, due to duplication of systems and the internal volume o˜ SWATH ships, tend to be higher for SWATH ships than for monohulls.

9. Active control systems are an extremely attractive system and should definitely be included in small SWATH ships.

10. The SWATH concepts examined have enclosed volumes larger than monohulls of similar displcement. As a result, these SWATH concepts have more volume than weight carrying capacity, and will probably have a number of designated voids.

11. Small helicopters, such as the HUGHES 500, if they were in the USCG inventory, could be landed and refueled, with a small amount of maintenance capability, on SWATH ships as small as 125 LTON, if properly configured. Larger helicopters, such as the HH-65A, can be landed and refueled, again, with a small amount of maintenance capability, on ships in the size range of 300-500 LTON, though they cannot be hangared. SWATH ships in the range of 500-600 LTON are probably of sufficient size to carry a hangar large enough to house the HH-65A, and a much larger maintenance capability. A SWATH ship of 750 LTON should be capable of fully supporting the LAMPS III helicopter, but it is unlikely that it could support all the weapons and equipment which comprise the LAMPS III mission suite.

12. The seakeeping of small SWATH ships is comparable to or better than that of much larger monohulls. This superior seakeeping provides the SWATH ship with much enhanced mission capability and availability

in heavy seas.

13. The smallest of the SWATH ships examined, 125 LTON, should be able to operate, though at a somewhat reduced mode, in a Sea State 5 and survive a Sea State 7. The 250-LTON concept should be fully operational in a Sea State 5 and survive a Sea State 7. The two larger SWATH ships should be fully operational in Sea State 6, and survive in a Sea State 7.

In summary, this report has attempted to demonstrate that SWATH ship technology is mature and that the SWATH concept provides opportunity for improvement in the operational capability of existing monohulls in all weather circumstances. The synergistic effects of the improved seakeeping of SWATH ships may well improve the area coverage and mission capability that can be acheived for a given investment level particularly if helicopters can be put to sea on small ships. It is felt that a more conclusive demonstration of this would be the construction and operation of a SWATH ship in day to day USCG missions.

ACKNOWLEDGEMENTS

The authors wish to thank Ms. Kathryn McCreight and Mr. Charles Turner of DTNSRDC, Carderock for the seakeeping analysis performed on each of the four SWATH concepts. They also wish to express their gratitude for the very complete propulsion system survey and analysis per-

formed by Mr. Samuel Shank of DTNSRDC, Annapolis. Finally they thank Mr. Larry Hawkins, of ASSET Inc., for his work on the outboard profiles of each of the concepts, the C3N suites and his meticulous care in preparing the graphics for this report. The in-depth work done in all cases was a great contribution to the parametric study.

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APPENDIX A

PAYLOADS ASSUMED FOR THE FOUR CONCEPTS DEVELOPED

PAYLOAD* ASSUMED FOR THE 125 LTON WPB

	Number	Description	Weight (LTONS)
Crew:	14	Personal effects	3.1
Stores:			0.3
Water:			2.1
Boats & Cranes:	2	21' Rigid Hull Inflatable	4.0
Armament:	2	50 caliber machine guns	0.06
	2	mounts	0.05
Ammunition:		for 50 caliber guns	0.45
TOTAL WEIGHT			10.1

* "Payload," as used here, describes basically the mission equipment of the ship.

PAYLOAD* ASSUMED FOR THE 250 LTON WPC

	Number	Description	Weight (LTONS)
Crew:	29	Personal effects	6.5
Stores:			1.1
Water:			4.3
Boats & Cranes:	2	21' Rigid Hull Inflatable	4.0
Armament:	1	MK 24 MOD 0 30mm (Emerlec)	2.4
Ammunition:	1900	rounds for 30mm	1.9
TOTAL WEIGHT			20.2

* "Payload," as used here, describes basically the mission equipment of the ship.

PAYLOAD* ASSUMED FOR THE 750 LTON WMEC

	Number	Description	Weight (LTONS)
Crew:	65	Personal effects	14.5
Stores:			5.5
Water:			9.7
Boats & Cranes:	2	21' Rigid Hull Inflatable	4.0
Armament:	2	MK 24 MOD 0 30 mm (Emerlec)	2.4
Ammunition:	1900	rounds for 30mm	1.9
Helicopter:	1	HH-65A	3.4
Helo Fuel:		JP-5	8.0
Helo Stores:			0.5
TOTAL WEIGHT			49.9

* "Payload," as used here, describes basically the mission equipment of the ship.

PAYLOAD* ASSUMED FOR THE 1250 LTON WHEC

	Number	Description	Weight (LTONS)
Crew:	90	Personal effects	20.1
Stores:			7.6
Water:			13.4
Boats & Cranes:	2	21' Rigid Hull Inflatable	4.0
Armament:	2	MK 75-76mm gun (Oto Melara)	7.3
Ammunition:	250	rounds for 76mm	3.0
Helicopter:	1	HH-65A	3.4
Helo Fuel:		JP-5	8.0
Helo Stores:			0.5
TOTAL WEIGHT			67.3

* "Payload," as used here, describes basically the mission equipment of the ship.

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APPENDIX B -- PROPULSION SYSTEMS SELECTED FOR THE SWATH CONCEPTS

Company Abbreviations

ALCO	Alco Power (USA)
AVCO	Avco Lycoming (USA)
CUMMINS	Cummins Engine Co. (USA)
DDA	Detroit Diesel Allison (USA)
FMP	Fairbanks Morse, Colt-Pielstick (USA)
GE	General Electric (USA)
MTU	Motoren-und Turbinen-Union (FDR)
PV	Paxman Diesels Ltd. (UK)
SACM	Societe Alsacienne de Constructions Mecaniques (France)
SEMT	SEMT-Pielstick (France)
SOLAR	Solar (USA)
UA	United Aircraft (USA)

PROPULSION SYSTEMS FOR THE 125 LTON CONCEPT

	15 knots	20 knots	25 knots	30 knots
	-DOMESTIC DIESELS-			
Manufacture	DDA	DDA	DDA	DDA
Model	8V92TI	8V92TI	12V149	16V149T
Rating (BHP)	570	570	800	1159
Speed (rpm)	2300	2300	1900	1800
Weight (lbs)	3625	3625	9000	11600
# Req.	2	4	4	4
	-EUROPEAN DIESELS-			
Manufacture	MTU	MTU	PV	MTU
Model	6V331TC92	8V331TC92	8CM	12V538TB92
Rating (BHP)	665	885	1800	2555
Speed (rpm)	2200	2200	1600	1790
Weight (lbs)	4070	5080	10180	11330
# Req.	2	2	2	2
	-GAS TURBINES-			
Manufacture	UA	SOLAR	SOLAR	SOLAR
Model	ST6L-77	SATURN	SATURN	SATURN
Rating (BHP)	654	1160	1160	1160
Speed (rpm)	33000	22300	22300	22300
Weight (lbs)	306	1250	1250	1250
# Req.	2	2	4	4

PROPULSION SYSTEMS FOR THE 250 LTON CONCEPT

-DOMESTIC DIESELS-

	15 knots	20 knots	25 knots	30 knots
Manufacturer	DDA	DDA	ALCO	ALCO
Model	12V-71TI	12V-149	12F251	16F251
Rating (BHP)	675	800	2800	4100
Speed (rpm)	2300	1900	1200	1200
Weight (lbs)	4860	9000	33000	42000
# Req.	2	4	2	2

-FOREIGN DIESELS-

	15 knots	20 knots	25 knots	30 knots
Manufacturer	MTU	PV	SACM	PV
Model	6V331TC92	8CM	19512V	16CM
Rating (BHP)	665	1800	2700	4000
Speed (rpm)	2200	1600	1560	1600
Weight (lbs)	4070	10180	13010	18525
# Req.	2	2	2	2

-GAS TURBINES-

	15 knots	20 knots	25 knots	30 knots
Manufacturer	UA	SOLAR	AVCO	GE
Model	ST6L-77	SATURN	TF35	LM500
Rating (BHP)	654	1160	3500	4900
Speed (rpm)	33000	22300	1540	7000
Weight (lbs)	306	1250	1435	1300
# Req.	2	4	2	2

PROPULSION SYSTEMS FOR THE 750 LTON CONCEPT

	15 knots	20 knots	25 knots	30 knots
		-DOMESTIC DIESELS-		
Manufacturer	CUMMINS	ALCO	ALCO	ALCO
Model	KTA-2300M	16F251	16F251	18F251
Rating (BHP)	940	4100	4100	4500
Speed (rpm)	1800	1200	1200	1100
Weight (lbs)	8460	42000	42000	49200
# Req.	2	2	4	4
		-FOREIGN DIESELS-		
Manufacturer	MTU	SACM	MTU	PV
Model	8V331TC92	19516V	16V538TB92	18CM
Rating (BHP)	885	3600	3410	4500
Speed (rpm)	2200	1560	1790	1600
Weight (lbs)	5080	16540	14740	20240
# Req.	2	2	4	4
		-GAS TURBINES-		
Manufacturer	SOLAR	GE	DDA	GE
Model	SATURN	LM500	570KB	LM500
Rating (BHP)	1160	4900	7300	4900
Speed (rpm)	22300	7000	11500	7000
Weight (lbs)	1250	1300	1490	1300
# Req.	2	2	2	4

PROPULSION SYSTEMS FOR THE 1250 LTON CONCEPT

	15 knots	20 knots	25 knots	30 knots
		-DOMESTIC DIESELS-		
Manufacturer	CUMMINS	ALCO	ALCO	FMP
Model	KTA-3067M	18F251	16V270	PC2.512V
Rating (BHP)	1250	4500	5248	7800
Speed (rpm)	1800	1100	1000	520
Weight (lbs)	10700	49200	52800	144200
# Req.	2	2	4	4
		-FOREIGN DIESELS-		
Manufacturer	PV	PV	MTU	SEMT
Model	8CM	18CM	20V956TB92	PA6
Rating (BHP)	1200	4500	5535	7200
Speed (rpm)	1600	1600	1410	1000
Weight (lbs)	8130	20240	35684	57640
# Req.	2	2	4	4
		-GAS TURBINES-		
Manufacturer	SOLAR	GE	GE	DDA
Model	SATURN	LM500	LM500	570KB
Rating (BHP)	1160	4900	4900	7300
Speed (rpm)	22300	7000	7000	11500
Weight (lbs)	1250	1300	1300	1490
# Req.	2	2	4	4

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APPENDIX C

COMMAND, CONTROL, NAVIGATION, SUITES ASSUMED FOR THE FOUR CONCEPTS

CRAFT: 125 LTON SWATH WPB

SWBS	NUMBER	EQUIPMENT	WEIGHT (lbs)	
		-NAVIGATION EQUIPMENT-		
423-1	1	LORAN C receiver	24	
		antenna assembly	5	
423-3	1	Navigation Patch Panel	5	
423-4	1	MF/HF (ADF) receiver	55	
		antenna assembly	36	
423-5	1	VHF (ADF) receiver	25	
		antenna assembly	25	
		indicator/control group	25	
423-6	1	UHF (ADF) receiver	25	
		antenna assembly	40	
		indicator/contol group	25	
424-1	1	Depth Sounder	52	
426-2	1	Gyro Compass MK 27/1	142	
426-5	1	Rodmeter Speed Log	94	
428-1	1	Frequency Standard	55	
				633
		-INTERNAL COMMUNICATIONS-		
432-2	10	Sound Powered Phone System	50	
433-1	60	Public Address & Alarm Systems	400	
433-2	5	Intercoms (21MC)	97	
433-3	1	Loud Hailer	18	
434	1	Entertainment System (1 TV, 1 Radio)	172	
436	1	Electric Alarm & Warning System	100	
439	1	Audio Recorder	125	
				962

125 LTON (cont.)

-EXTERNAL COMMUNICATIONS-

441-1	1	MF Transmitter System	48	
		coupler	19	
		antenna	140	
441-2	1	MF Receiver	30	
		antenna assembly	120	
441-3	1	HF Transceiver System	250	
		antenna	100	
		antenna coupler	80	
441-5	1	VHF AM Transceiver	22	
		antenna	50	
441-6	1	VHF FM Transceiver	24	
441-7	1	UHF LOS Transceiver	151	
		spare antenna	5	
441-11	1	Communication Switchboard	110	
441-12	2	Remote Operator Position	34	
441-15	1	Voice Privacy System (non-crypto)	30	
				1213

-VISUAL & AUDIBLE-

443-6	1	Infrared trans/receive set	125	
443-8	2	12" Signal Search lights	100	
				225

-RADAR-

451-1	1	AN/SPS-55	1100	
				1100

125 LTON (cont.)

-METEOROLOGICAL SYSTEM-

494-1	1	Anemometer	53	
494-2	1	Psychrometric System	16	
494-3	1	Barometric Pressure System	11	
				80

TOTAL COMMAND, CONTROL, COMMUNICATION, NAVIGATION WEIGHT 4213 lbs

1.9 LTONS

CRAFT: 250 LTON SWATH WPB

SWBS	NUMBER	EQUIPMENT	WEIGHT (lbs)
		-NAVIGATION EQUIPMENT-	
423-1	1	LORAN C receiver	24
		antenna assembly	5
423-3	1	Navigation Patch Panel	5
423-4	1	MF/HF (ADF) receiver	55
		antenna assembly	36
423-5	1	VHF (ADF) receiver	25
		antenna assembly	25
		indicator/control group	25
423-6	1	UHF (ADF) receiver	25
		antenna assembly	40
		indicator/contol group	25
424-1	1	Depth Sounder	52
426-2	1	Gyro Compass MK 27/1	142
426-5	1	Doppler Speed Log	215
428-1	1	Frequency Standard	55
			754
		-INTERNAL COMMUNICATIONS-	
432-1	10	Telephone System	737
432-2	10	Sound Powered Phone System	55
433-1	20	Public Address & Alarm Systems	668
433-2	8	Intercoms (21MC)	132
433-3	1	Loud Hailer	33

250 LTON (cont.)

434	1	Entertainment System 19" TV	72	
		antenna	7	
	3	stereo receiver	90	
	1	cassette recorder	15	
	6	speakers	150	
436	1	Electric Alarm & Warning System	150	
439-1	1	LLTV	50	
439	1	Audio Recorder	125	
				2284

-EXTERNAL COMMUNICATIONS-

441-1	1	MF Transmitter system	48	
		antenna	140	
		coupler	19	
441-2	1	MF Receiver	30	
		antenna assembly	120	
441-3	2	HF Transceiver System	500	
		antenna	200	
		antenna coupler	160	
441-5	1	VHF AM Transceiver	22	
		antenna	50	
441-6	1	VHF FM Transceiver	24	
441-7	2	UHF LOS Transceiver	302	
		spare antenna	5	
441-11	1	Communication Switchboard	110	
441-12	3	Remote Operator Position	51	
441-13	2	Loudspeakers	20	
441-14	1	Reproduction System (copier)	230	
441-15	1	Voice Privacy System (non-crypto)	30	
441-16	1	System Monitor Transmission Panel	25	
	7	Bidirectional couplers	35	
				2121

250 LTON (cont.)

-VISUAL & AUDIBLE-

443-6	1	Infrared trans/receive set	125	
443-8	2	12" Signal Search lights	100	
				225

-SECURE VOICE SYSTEMS-

446-1	1	HF security	30	
	1	UHF security	100	
446-6	1	Secure offline	70	
				200

-RADAR-

451-1	1	AN/SPS-55	1100	
				1100

-BATHYTHERMOGRAPH SYSTEM-

465-1	1	AN/SSQ-61 XBT (20 probes)	265	
				265

-GUN FIRE CONTROL SYSTEM-

481-1	1	Radar Gun Fire Control System MK 93 MOD 0	930	
481-2	2	Optical Director MK 35 MOD 0	1524	
481-3	1	Director Junction Box	325	
481-4	2	Gun Mount Junction Box	22	
481-5	1	Stable Element Gyro & Control	129	
				2930

250 LTON (cont.)

-METEOROLOGICAL SYSTEM-

494-1	1	Anemometer	53	
494-2	1	Psychrometric System	16	
494-3	1	Barometric Pressure System	11	
				80

TOTAL COMMAND, CONTROL, COMMUNICATION, NAVIGATION WEIGHT	9959 lbs
	4.4 LTONS

CRAFT: 750 LTON SWATH WPB

SWBS	NUMBER	EQUIPMENT	WEIGHT (lbs)
		-NAVIGATION EQUIPMENT-	
423-1	1	LORAN C receiver	24
		antenna assembly	5
423-2	1	OMEGA receiver	30
		antenna assembly	6
423-3	1	Navigation Patch Panel	5
423-4	1	MF/HF (ADF) receiver	55
		antenna assembly	36
423-5	1	VHF (ADF) receiver	25
		antenna assembly	25
		indicator/control group	25
423-6	1	UHF (ADF) receiver	25
		antenna assembly	40
		indicator/contol group	25
424-1	1	Depth Sounder	372
426-2	3	Gyro Compass WSN-2	615
426-5	1	Doppler Speed Log	215
428-1	1	Frequency Standard	55
			1583
		-INTERNAL COMMUNICATIONS-	
432-1	20	Telephone System	787
432-2	20	Sound Powered Phone System	60
433-1	40	Public Address (1MC & 6MC) & Alarm System	852
433-2	10	Intercoms (21MC)	148
433-3	3	Loud Hailer	33

750 LTON (cont.)

434	2	Entertainment System 19" TV	144	
		rotor and antenna	7	
	1	distribution amplifier	20	
	1	video recorder	45	
		distribution amplifier	10	
	4	stereo receiver	120	
	1	stereo cassette recorder	15	
	2	stereo 8 track player	20	
	10	speakers	250	
	1	AM distributed amplifier	12	
436	1	Electric Alarm & Warning System	150	
439-1	1	LLTV	50	
439	1	Audio Recorder	125	
				2848

-EXTERNAL COMMUNICATIONS-

441-1	1	MF Transmitter System	48
		antenna assembly	251
441-2	1	MF Receiver	30
		antenna assembly	120
441-3	3	HF Transceiver System	750
	2	antenna	200
	2	antenna coupler	160
	1	remote control	29
	1	Miniloop MLA-1/E/A	240
	1	MLA-2/D	212
441-4	2	HF receiver system	60
	1	antenna assembly	100
	1	coupler	207
441-5	1	VHF AM Transceiver	22
		antenna	50
441-6	1	VHF FM Transceiver	24

750 LTON (cont.)

441-7	3	UHF LOS Transceiver	453	
	1	RATT	151	
	1	SATCOM	151	
	1	spare antenna	5	
441-8	1	Satellite Receiving System		
	4	antenna	52	
	4	amplifier-converter	52	
	1	combiner-demodulator	81	
	1	demultiplexer	72	
	1	alarms and buzzers	7	
441-9	2	Satellite Directional Antenna	935[3]	
441-10	1	TACAN (complete)	927	
441-11	1	Communication Switchboard	110	
441-12	6	Remote Operator Position	150	
441-13	3	Loudspeakers	30	
441-14	1	Reproduction System (copier)	230	
441-15	1	Voice Privacy System (non-crypto)	30	
441-16	1	System Monitor Transmission Panel	25	
	12	Bidirectional couplers	60	
				6024

-VISUAL & AUDIBLE-

443-6	1	Infrared trans/receive set	125	
443-7	1	High Intensity Searchlight & Pedestal	310	
443-8	2	12" Signal Search lights	100	
				535

750 LTON (cont.)

-TELETYPE & FACSIMILE-

445-1	1	Fax Recorder	120	
445-2	1	Teletype receive and transmit system	213	
445-3	1	Teletypwriter sets	290	
	1	Keyboard display	360	
	1	Receive only printer	135	
				1118

-SECURE VOICE SYSTEMS-

446-1	1	FltSatCom Secure	155	
	1	HF secure	29	
	2	UHF Secure	195	
	1	USCG Environmental Equip. Cabinet	450	
446-2	1	Secure voice communication switchboard	125	
446-3	3	Secure transmit and receive TTY	381	
	2	Receive only	454	
	1	Switch panel	7	
446-4	1	Secure TTY Patch Panel	125	
446-5	1	Secure IFF		
446-6	1	Secure offline	70	
				1991

-RADAR-

451-1	1	Surface: AN/SPS-67	785	
452-1	1	Air: AN/SPS-58	1582	
		combining antenna (SPS 10)	475	
455-1	1	IFF	854	
				3696

750 LTON (cont.)

-BATHYTHERMOGRAPH SYSTEM-

465-1	1	AN/SSQ-61 XBT (20 probes)	265	
				265

-GUN FIRE CONTROL SYSTEM-

481-1	1	Radar Gun Fire Control System MK 93 MOD 0	930	
481-2	2	Optical Director MK 35 MOD 0	1524	
481-3	1	Director Junction Box	325	
481-4	1	Gun Mount Junction Box	22	
481-5	1	Stable Element Gyro & Control	129	
				2930

-METEOROLOGICAL SYSTEM-

494-1	1	Anemometer	53	
494-2	1	Psychrometric System	16	
494-3	1	Barometric Pressure System	11	
				80

TOTAL COMMAND, CONTROL, COMMUNICATION, NAVIGATION WEIGHT 21070 lbs

9.4 LTON

CRAFT: 1250 LTON SWATH WPB

SWBS	NUMBER	EQUIPMENT	WEIGHT (lbs)	
		-NAVIGATION EQUIPMENT-		
423-1	2	LORAN C receiver	48	
		antenna assembly	5	
423-2	1	OMEGA receiver	30	
		antenna assembly	6	
423-3	1	Navigation Patch Panel	5	
423-4	1	MF/HF (ADF) receiver	55	
		antenna assembly	36	
423-5	1	VHF (ADF) receiver	25	
		antenna assembly	25	
		indicator/control group	25	
423-6	1	UHF (ADF) receiver	25	
		antenna assembly	40	
		indicator/contol group	25	
424-1	1	Depth Sounder	372	
426-2	3	Gyro Compass WSN-2 (2 repeaters)	801	
426-5	1	Doppler Speed Log	215	
428-1	1	Frequency Standard	55	
				1793
		-INTERNAL COMMUNICATIONS-		
432-1	30	Telephone System	842	
432-2	50	Sound Powered Phone System	389	
433-1	75	Public Address (1MC & 6MC) & Alarm System	1419	
433-2	12	Intercoms (21MC)	213	
433-3	6	Loud Hailer	53	

1250 LTON (cont.)

434	2	Entertainment System 19" TV	144
	3	17" TV	192
	1	rotor and antenna	7
	1	video recorder	45
	2	distributor amplifier	20
	1	4 way signal amplifier	1
	6	2 way signal amplifier	3
	6	antenna switch	3
	6	VHF-FM-UHF signal splitter	3
	5	stereo receiver	150
	2	stereo cassette recorder	30
	3	stereo 8 track player	30
	1	stereo 8 track recorder	20
	12	speakers	300
	1	AM distributed amplifier	12
	4	2 way signal splitter	2
436	1	Electric Alarm & Warning System	150
439-1	1	LLTV	50
439	1	Audio Recorder	125
			4203

-EXTERNAL COMMUNICATIONS-

441-1	2	MF Transmitter System	96
		antenna assembly	251
441-2	2	MF Receiver	60
		auto alarm	27
		antenna group	110
441-3	4	HF Transceiver System	1000
	2	antenna	200
	2	antenna coupler	160
	2	remote control	58
	1	Miniloop MLA-1/E/A	240
	1	MLA-2/D	212
441-4	4	HF receiver system	120
	2	rigid antenna assembly	200
	2	coupler group	414

1250 LTON (cont.)

441-5	2	VHF AM Transceiver	44	
	2	antenna	100	
441-6	3	VHF FM Transceiver	72	
441-7	4	UHF LOS Transceiver	604	
	1	RATT	151	
	1	SATCOM	151	
		spare antenna	5	
441-8	1	Satellite Receiving System		
	4	antenna	52	
	4	amplifier-converter	52	
	1	combiner-demodulator	81	
	1	demultiplexer	72	
	1	alarms and buzzers	7	
441-9	2	Satellite Directional Antenna	935	
441-10	1	TACAN (complete)	927	
441-11	1	Communication Switchboard	110	
441-12	10	Remote Operator Position	250	
441-13	4	Loudspeakers	40	
441-14	1	Reproduction System (copier)	230	
441-15	2	Voice Privacy System (non-crypto)	60	
441-16	1	System Monitor Transmission Panel	25	
	16	Bidirectional couplers	80	
				7196

-VISUAL & AUDIBLE-

443-6	1	Infrared trans/receive set	125	
443-7	1	High Intensity Searchlight & Pedestal	310	
443-8	2	12" Signal Search lights	100	
				535

1250 LTON (cont.)

-TELETYPE & FACSIMILE-

445-1	1	Fax Recorder	120	
445-2	1	Teletype receive and transmit system	213	
445-3	1	Recieve only printer	135	
	1	Keyboard display	290	
	2	Keyboard display printer	720	
	1	Keyboard display printer	230	
445-4	1	Naval Modular auto comm. system	795	
				2503

-SECURE VOICE SYSTEMS-

446-1	1	FltSatCom Secure	155	
	2	HF secure	58	
	3	UHF Secure	333	
	1	USCG Environmental Equip. Cabinet	450	
446-2	1	Secure voice communication switchboard	125	
446-3	4	Secure TTY transmit and receive	464	
	3	receive only TTY	577	
	1	switch panel	7	
446-4	1	Secure TTY Patch Panel	125	
446-5	1	Secure IFF		
446-6	1	Secure offline	70	
				2364

-RADAR-

451-1	1	Surface: AN/SPS-67	785	
452-1	1	Air: AN/SPS-58	1582	
		combining antenna (SPS 10)	475	
455-1	1	IFF	854	
				3696

1250 LTON (cont.)

		-BATHYTHERMOGRAPH SYSTEM-		
465-1	1	AN/SSQ-61 XBT	265	
				265
		-PASSIVE ECM-		
472-1	1	SLQ 31 or 32	2278	
472-2	1	Radial set	10	
				2288
		-DECOYS-		
473-1	1	NIXIE AN/SLQ-25	2095	
474-1	2	Decoy Launch (RBOC)	865	
				2960
		-DEGAUSSING-		
475-1	1	Degaussing System	TBD	
		-GUN FIRE CONTROL SYSTEM-		
481-1	1	Gun Fire Control System MK 92	5817	
481-2	1	Optical Surveillance	640	
489-1	1	Fire Control Switchboard	600	
		-METEOROLOGICAL SYSTEM-		
494-1	1	Anemometer	53	
494-2	1	Psychrometric System	16	
494-3	1	Barometric Pressure System	11	
				80

TOTAL COMMAND, CONTROL, COMMUNICATION, NAVIGATION WEIGHT 34940 lbs

15.6 LTON

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